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NOTICES

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SEED PRODUCTION STUDIES

III. THE EFFECT OF NITROGENOUS FERTILIZER, APPLIED AT DIFFERENT RATES AND DATES, ON SEED PRODUCTION IN TIMOTHY (*Phleum pratense* L.)

By J. P. LAMBERT, Grasslands Division, Department of Scientific and Industrial Research, Gore

(Received for publication, 8 September 1955)

Summary

In timothy (*Phleum pratense* L.), the number of panicles was increased by the application of nitrogenous fertilizer. At the 2 cwt. rate, the spring application produced most panicles. Maximum panicle production was reached with the 4 cwt. application, and 6 cwt. did not result in a further increase. Time of application had no effect, except at the 2 cwt. rate, when the spring dressing was most effective.

Lodging increased with increasing rate of application and with spring dressings.

The weight per 1,000 seeds was little affected, but there was a trend towards increase with spring applications, and with increasing rate.

The number and weight of viable seed per panicle were increased with increase in rate and with spring applications. The 2 cwt. autumn and split applications tended to reduce the number and weight per panicle. Maximum weight and number of seeds per panicle followed 6 cwt. as a split dressing.

Seed yield per acre was increased with increase in rate and with spring applications; 2 cwt. in spring was as effective as 4 cwt. or 6 cwt. in spring; 2 cwt. in autumn or as a split dressing did not increase seed yield. Only when 6 cwt. was applied as a split dressing was there an increase above the yield from the 2 cwt. spring dressing.

INTRODUCTION

The average annual production of timothy seed (*Phleum pratense* L.) in New Zealand for the years 1949 to 1951 was 168 lb. per acre (N.Z. Census and Statistics 1952). Harbord (1949) stated that, in Southland, yields of nearly 1,000 lb. have been harvested, and that a good yield was up to 500 lb. In Britain, yields of 300–400 lb. per acre were stated to be most frequently expected (Welsh Plant Breeding Station, 1944), while Andersen (1949) gave an average Danish yield as 380 lb. per acre.

Little or no nitrogenous fertilizer appears to be used on timothy seed crops in New Zealand. Evans (1937), in Britain, considered that 1 cwt. per acre of nitro-chalk in autumn and 2 cwt. in spring produced satisfactory results on timothy as well as other grass seed crops. Schwanbom and Fröier (1949) stated that, in Denmark, applications up to 54 lb. N per acre gave increased yields, and, in other experiments, nitrate of soda equivalent to 140, 290, and 430 lb. sulphate of ammonia produced increases of 60, 80, and 100 lb. seed per acre. They also stated that, in Sweden, 270 lb. nitrate of soda, equivalent to 220 lb. sulphate of ammonia, had been most suitable, and that the equivalent of 450 and 650 lb. sulphate of ammonia had given insignificant increases in yield, and both of these rates had resulted in lodging. In Norway they reported that the equivalent of 430 lb. sulphate of ammonia was the most economic rate. Andersen (1949) stated that, in Denmark, the equivalent of 240 to 300 lb. sulphate of ammonia was advisable. The best season of application was not known, but experiments had shown that there was no advantage in applying a part in autumn, and that the time of spring application could vary greatly without seed yield being affected. Since the present experiment began, Jones (1953) has concluded that 6 cwt. per acre of sulphate of ammonia, the heaviest dressing he applied, may not be the maximum rate of application to give increases on light land, while Evans (1954), working on Lower Lias clay, found that 4 cwt. sulphate of ammonia per acre had little effect on seed yield. Fulkerson *et al.* (1951), in Canada, found no significant effect of nitrogen, in any of five forms, though increases in cocksfoot seed yield were measured.

The present experiment was designed to study the effect of applying nitrogenous fertilizer at three different rates and at different times; all in autumn, all in spring, or equally divided between autumn and spring.

Experimental Design and Procedure

The experiment was conducted at the Grasslands Division Station at Gore, on the same alluvial soil as described in Part I.

The timothy had been sown in rows 24 in. apart in February 1949, at the rate of 2 lb. per acre. This timothy was for nucleus seed production, and was a leafy type, of New Zealand pedigree strain (Gorman 1950). The first harvest was in late February 1950, with a yield of 275 lb. per acre of clean seed. Sulphate of ammonia, at 2 cwt. per acre, was applied in September 1950, and the second pre-trial harvest made in late February 1951, with a yield of 212 lb. per acre. Following this harvest, the nitrogen treatments were begun. Superphosphate was applied at sowing, and subsequently each autumn, at the rate of 2 cwt. per acre.

The plots were 4 rows wide and 105 ft. long. Treatments were the same as described in Part I for cocksfoot, as follows:

Treatments were replicated four times in randomized blocks. Autumn applications were made at the end of March, and spring applications in early September. Sulphate of ammonia was used in the first two years, and nitro-lime in the third year. At harvest, the two outside rows were discarded from each plot, together with eighteen inches from each end. Stratified sampling was used, five samples, each of two

SULPHATE OF AMMONIA OR NITRO-LIME. CWT. PER ACRE.

Treatment No.	Autumn	Spring	Total
1	0	0	0
2	2	0	2
3	1	1	2
4	0	2	2
5	4	0	4
6	2	2	4
7	0	4	4
8	6	0	6
9	3	3	6
10	0	6	6

feet, being harvested from each plot row in 1952, and eight samples of one foot per plot row in 1953 and 1954. Samples were then treated as for the cocksfoot samples in Parts I and II, except that the seed still retained within the glumes after threshing was put through a small huller. Purity and germination percentages of the seed samples, and weight per 1,000 seeds, were determined by the Seed Testing Station, Department of Agriculture, Palmerston North. All seed data presented were calculated on a basis of viable seed or 100% germination. The addition of 10% to the weight of viable seed per acre will give the approximate machine-dressed weights.

RESULTS

Maturity

In some of the plots receiving the higher rates of nitrogen in spring, maturity was delayed for up to a week. The amount of leaf was also increased in these plots.

Lodging

It was obvious that differences in the amount of lodging were occuring. The amount of lodging was scored, on a 0–10 scale, each year prior to harvesting. These data are presented in Table 2.

Purity and Germination

No significant effects of treatments were detected and data are not presented.

Interaction of Rate and Date of Application

Significant interaction occurred in the number of viable seeds per panicle (Table 4), in the mean of the three years. Significant interaction was detected also in the weight of viable seed per acre (Table 5), in the 1952 and 1954 harvests and in the mean of the three years. There were indications of interaction in the 1953 harvest in both tables, but the differences were not significant.

TABLE 1. NUMBER OF PANICLES PER FOOT OF ROW

Date	Rate cwt. per acre	1952	1953	1954	Mean
Control	0	67.6	50.9	52.9	57.0
Autumn	2	83.9	81.0	66.8	77.2
Split	2	83.0	80.0	73.9	79.0
Spring	2	76.2	86.9	95.8	86.3
Autumn	4	73.9	82.0	104.0	86.6
Split	4	77.1	83.7	103.1	88.0
Spring	4	68.4	76.0	101.4	81.9
Autumn	6	75.5	77.6	98.7	83.9
Split	6	68.8	75.7	96.1	80.2
Spring	6	67.7	77.0	100.7	81.8
S.E. individual means ±		4.0	4.7	7.8	3.3
Sig. diff. at 5% level		11.7	13.7	22.6	9.9
2 cwt. mean		81.0	82.6	78.8	80.8
4 cwt. mean		73.1	80.6	102.8	85.5
6 cwt. mean		70.7	76.8	98.5	82.0
Autumn mean		77.8	80.2	89.8	82.5
Split mean		76.3	79.8	91.0	82.4
Spring mean		70.8	79.9	99.3	83.3
S.E. Rate and Date means ±		2.3	2.7	4.5	2.0
Sig. diff at 5% level		6.7	—	13.1	—
Linear trends: Rates		**	—	**	—
Linear trends: Dates		*	—	—	—

Results of tests for linear trend: — not significant
(*) sig. at 10%
* „ „ 5%
** „ „ 1%

TABLE 2. LODGING SCORE, IMMEDIATELY BEFORE HARVEST
(0 = no lodging. 10 = fully lodged.)

Date	Rate cwt. per acre	1952	1953	1954	Mean
Control	0	1.5	2.5	0.8	1.6
Autumn	2	2.5	2.3	1.0	1.9
Split	2	3.0	2.3	1.5	2.3
Spring	2	5.8	4.3	2.3	4.1
Autumn	4	5.8	4.5	3.0	4.4
Split	4	5.5	3.0	2.8	3.8
Spring	4	7.3	5.5	3.0	5.3
Autumn	6	9.3	5.0	3.0	5.8
Split	6	8.8	6.3	4.0	6.4
Spring	6	8.3	5.5	5.5	6.4
S.E. individual means ±		1.0	0.9	0.8	0.7
Sig. diff. at 5% level		2.9	2.7	2.4	2.2
2 cwt. mean		3.8	2.9	1.6	2.8
4 cwt. mean		6.2	4.3	2.9	4.5
6 cwt. mean		8.8	5.6	4.2	6.2
Autumn mean		5.9	3.9	2.3	4.0
Split mean		5.8	3.9	2.8	4.2
Spring mean		7.1	5.1	3.6	5.3
S.E. Rate and Date means ±		0.6	0.5	0.5	0.4
Sig. diff. at 5% level		1.7	1.6	1.4	1.2
Linear trends: Rates		**	**	**	**
Linear trends: Dates		—	—	(*)	*

Spring applications resulted in significantly the highest number of viable seeds per panicle, in the three-year mean, at the 2 cwt. and 4 cwt. rates. At the 6 cwt. rate, the number resulting from the split application was significantly higher than from the autumn dressing, and higher, but not significantly, than that following the spring dressing.

The weight of seed per acre was increased significantly in 1952 following increases in rate of autumn and split applications from 2 cwt. to 4 cwt., and again when they were increased to 6 cwt. Increasing the rate of the spring application did not result in corresponding gains in yield. In the 1954 harvest, changing the rate from 2 cwt. to 4 cwt. resulted in significant increases in yield from the autumn and split dressings. Only from the split dressing was a further gain made by increasing the rate to 6 cwt. There was no advantage in raising the spring dressing above 2 cwt. In the three-year mean the interaction was similar to that of the 1954 harvest.

No interaction of rate and date of application was detected in the number of panicles (Table 1), lodging (Table 2), or weight per 1,000 seeds (Table 3). Table 6 summarizes Tables 1–5, and includes a summary of weight of viable seed per panicle.

TABLE 3 WEIGHT (MG.) OF 1000 SEEDS.

Rate or Date of Application	1952	1953	1954	Mean
Control—no nitrogen	284	298	296	293
2 cwt.	287	298	281	289
4 cwt.	290	315	299	301
6 cwt.	295	319	298	304
Autumn	288	312	283	294
Split	293	307	292	297
Spring	291	313	302	302
S.E. Rate and Date Means ±	4.0	5.6	4.7	3.5
Sig. diff. at 5% level	—	16.2	13.7	12.2
Linear trend: Rates	—	*	*	**
Linear trend: Dates	—	—	**	—

TABLE 4. NUMBER OF VIABLE SEEDS PER PANICLE.

Date	Rate cwt. per acre	1952	1953	1954	Mean
Control	0	269	330	179	259
Autumn	2	253	256	130	213
Split	2	260	250	135	215
Spring	2	344	359	202	302
Autumn	4	341	351	173	288
Split	4	320	310	157	262
Spring	4	420	430	177	342
Autumn	6	375	404	185	321
Split	6	429	488	232	383
Spring	6	440	426	182	349
S.E. individual mean ±		22.1	34.3	22.2	20.5
Sig. diff. at 5% level		64.4	100.1	64.8	59.8
2 cwt. mean		286	288	156	243
4 cwt. mean		360	364	169	297
6 cwt. mean		415	439	200	351
Autumn mean		323	337	163	274
Split mean		336	349	175	287
Spring mean		401	405	187	331
S.E. Rate and Date means ±		12.7	19.3	12.8	11.8
Sig. diff. at 5% level		37.2	55.8	37.4	34.5
Linear trends: Rates		**	**	*	**
Linear trends: Dates		**	*	—	**

TABLE 5. WEIGHT (LB.) OF VIABLE SEED PER ACRE.

Date	Rate cwt. per acre	1952	1953	1954	Mean
Control	0	250	271	182	234
Autumn	2	283	308	131	241
Split	2	285	295	147	242
Spring	2	364	476	261	367
Autumn	4	346	447	279	357
Split	4	334	391	231	319
Spring	4	400	505	272	392
Autumn	6	394	486	248	376
Split	6	426	556	330	437
Spring	6	406	493	256	385
S.E. individual means ±		55.1	44.4	30.9	28.1
Sig. diff. at 5% level		80.4	129.5	90.2	82.1
2 cwt. mean		311	360	180	283
4 cwt. mean		360	448	261	356
6 cwt. mean		409	512	278	400
Autumn mean		341	414	219	325
Split mean		348	414	236	333
Spring mean		390	491	263	381
S.E. Rate and Date means ±		31.8	25.6	17.8	16.2
Sig. diff. at 5% level		46.4	74.7	52.1	47.4
Linear trends: Rates		**	**	**	**
Linear trends: Dates		*	*	(*)	*

TABLE 6. SUMMARY OF OVERALL MEANS FOR THE THREE HARVESTS 1952–54.

Rate or Date of Application	No. Panicles per Foot	Lodging Score 0-10	Weight per 1000 Seeds mg.	Weight of Viable Seed per Panicle mg.	No. of Viable Seeds per Panicle	Weight of Viable Seed per Acre. lb.
No nitrogen	57.0	1.6	293	77	259	234
2 cwt.	80.8	2.8	289	72	243	283
4 cwt.	85.5	4.5	301	90	297	356
6 cwt.	82.0	6.2	304	108	351	400
Autumn	82.5	4.0	294	83	274	325
Split	82.4	4.2	297	87	287	333
Spring	83.3	5.3	302	100	331	381

DISCUSSION

The failure of the 2-cwt. autumn and split dressing to produce increases in seed yield above the yield of the control is attributed mainly to the low number of seeds per panicle from these treatments. Weights per 1,000 seeds were slightly lower than that of the control, so that the weight of seed per panicle was also low. Though the number of panicles produced was higher than the control number, this could not compensate for the low weight per panicle.

The 2 cwt. spring treatment, on the other hand, produced an increasingly greater number of panicles as the trial proceeded, with greater numbers of seeds per panicle. A tendency towards a lowering of the weight per 1,000 seeds almost balanced the rise in seed numbers, but the increase in panicle numbers more than compensated.

Increases in the rate of spring dressing to 4 cwt. and 6 cwt. did not lead to a further increase in panicle numbers, or number of seeds per panicle. There was a small increase in weight per 1,000 seeds up to 4 cwt. The yield of seed from 4 cwt. and 6 cwt. spring dressings did not, as a result, differ from the yield from the 2 cwt. application.

Increase in the autumn rate to 4 cwt. did not increase the number of panicles, except in 1954 when the increase was significant. The number of seeds per panicle rose significantly, but the weight per 1,000 seeds was increased significantly only in 1954. The increase in seed yield is due, therefore, mainly to the increase in the number of seeds per panicle. Raising the autumn rate to 6 cwt. further increased the number of seeds per panicle, but not significantly, and not sufficiently to increase the seed yield.

When the split dressing was increased to 4 cwt., a significant increase in panicle numbers occurred only in 1954. The weight per 1,000 seeds was not increased. The increase in number of seeds per panicle was sufficient to cause a rise in seed yield which however was not quite significant. The yield from the 4 cwt. split dressing was lower,

but did not differ significantly from those of the 2 cwt. spring or 4 cwt. autumn applications. Further increase in rate to 6 cwt. resulted in a marked and significant increase in the number of seeds per panicle each year. No increases in the number of panicles or the weight per 1,000 seeds were measured. The large and significant increase in seed yield was due to the increase in number of seeds per panicle.

Under the conditions of this trial, there was no benefit to be gained from an application of more than 2 cwt. when applied in spring. This was as effective as 4 cwt. applied in autumn or as a split dressing, or 6 cwt. applied in autumn. The split dressing was most efficient applied at 6 cwt. per acre, and there was nothing to be gained by applying a split dressing under 6 cwt.

These results differ from those of Evans (1954), who found that applications of nitrogenous fertilizer either depressed panicle production, or had no effect. Increases in weight of seed per tiller made up for any reduction in tiller numbers, so that nitrogen treatments made little or no difference to seed yield.

Jones (1953), on the other hand, concluded that timothy on light land should be manured heavily with a nitrogenous fertilizer, and that there was nothing to suggest that 6 cwt. was the maximum application rate at which response would stop. He also stated that the number of ears was increased by a 2 cwt. application, but heavier applications did not materially increase ear numbers. This agrees more closely with the results of the present trial, except that here there was little response beyond the 2 cwt. spring dressing, and it was not until 6 cwt. was applied as a split dressing that a further increase in seed yield occurred.

The timothy crop in Southland is usually grown on heavier soil than that of the present trial. This, together with often heavy winter and spring stocking and its consequent manuring, probably accounts for the yields quoted by Harbord (1949).

The serious lodging associated with the 6 cwt. split dressing would make caution necessary in its use. Lodging is likely to be more prevalent in Southland than in Canterbury, because summer rainfall is generally higher. The rainfall for January 1954 was below average, rain falling mainly in the middle of the month, with the first and latter parts of the month very dry. This is considered to be the reason for the reduction in the number of seeds per panicle, and the weight per panicle and per acre, in the 1954 harvest. Panicle numbers and weight per 1,000 seeds were not affected. Timothy is about a month later in flowering than cocksfoot, and investigation into the effect of later spring applications on both seed yield and lodging are necessary. The opinion of some growers is that the leafy pedigree timothy is more prone to lodging than the "commercial" type which it replaces. Comparative tests have not been made, but if this is the case it may be possible for the plant breeder to develop a strain less liable to lodging, without losing the valuable leafiness and long growing season.

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ROSE-MOSAIC VIRUS IN NEW ZEALAND

By P. R. Fry and J. A. Hunter, Plant Diseases Division, Department of Scientific and Industrial Research, Auckland

(Received for publication, 31 October 1955)

Summary

Rose mosaic has been found to be distributed throughout New Zealand. It occurs in two distinct symptom forms, vein banding and line pattern, and can be transmitted from diseased to healthy bushes by budding.

Transmission studies indicate that vein banding and line pattern symptoms are caused by distinct virus entities. The available evidence does not indicate whether they are separate viruses or different strains of the same virus.

Introduction

Mosaic diseases of the rose have been known in Europe since the middle of last century and were first recorded in the United States by White (1928, 1932) who showed that they were transmissible by budding. Brierley and Smith (1940) showed that rose mosaic was not transmitted by any of the 31 species of insect they tested. They also showed that the disease was not transmitted from rose to rose by mechanical inoculation.

The rose mosaics described here occur throughout New Zealand, having been noted in Auckland, Hamilton, Gisborne, Napier, Palmerston North, New Plymouth, Christchurch, and Dunedin.

Symptoms

Symptoms may appear on all leaves of a plant but are often found on a few leaves only. They are more common on leaves produced

Fig. 1.—Vein-banding symptoms of rose mosaic on Texas Centennial. Healthy leaf on right × ⅔.

—Photo H. L. Powell.

in spring than on those that develop in the warmer summer months. Distortion of leaves, reduction in flowering capacity, or loss of vigour have not been observed.

Leaf symptoms are of two types:

(a) Vein banding (Figs. 1 and 2). Creamy white to yellow bands along the veins may occur in isolated areas of the leaflet or in a strip round the margin, or the entire vein network may be affected.

Fig. 2.—Vein-banding symptoms of rose mosaic on *Rosa multiflora* stock (left) and Charlotte Armstrong. × ¾.

—*Photo H. L. Powell.*

(b) Line pattern (Figs. 3 and 4). Narrow wavy lines or broad bands of pale-green, yellowish, or creamy white tissue form irregular patterns on the leaflet. These may take the form of spots or blotches, or appear as wavy lines or bands of irregular outline extending across the leaflet in a more or less zigzag manner.

Vein-banding symptoms have been observed on varieties Mme. A. Meilland (Peace), Texas Centennial, Charlotte Armstrong, Shot Silk, and Cecile Brunner, and those of the line-pattern type on Majorca, Pinocchio, and Mrs. O. G. Orphan.

Fig. 3.—Line pattern symptoms of rose mosaic on Pinocchio. × 4/5.
—*Photo S. A. Rumsey.*

Fig. 4.—Line-pattern symptoms of rose mosaic on Majorca. ×½.
—*Photo S. A. Rumsey.*

TRANSMISSION

To ascertain whether the above symptoms were transmissible, buds from affected plants were inserted into healthy plants of *Rosa multiflora* stock or into varieties Autumn or Ophelia. In all cases symptoms were reproduced in growth from the inserted buds.

Results given in Table 1 show that symptoms were transmitted to the stock plant in six out of eight tests. Plants budded with line-pattern material developed line-pattern symptoms twelve months after insertion of buds. Those receiving buds from vein-banding plants developed vein-banding symptoms in the second spring or summer after budding.

The range of symptoms occurring on roses in New Zealand includes most of those described by White (1932) and Brierley and Smith (1940) as due to rose mosaic virus. The vein-banding and line-pattern symptoms

TABLE 1. Transmission of Rose Mosaic by Budding

Symptom Type	Source of Infected Buds	Stock	Result
Line pattern	Pinocchio	Autumn, *R. multiflora*	+
	„	Ophelia, *R. multiflora*	+
	„	*R. multiflora*	+
	Majorca	„	+
	Mrs. O. G. Orphan	„	—
Vein banding	Cecile Brunner	„	+
	Charlotte Armstrong	„	+
	Texas Centennial	„	—

\+ Symptom transmitted

— Symptom not transmitted

described above have been transmitted independently and have retained their identity on the new hosts. It is apparent therefore, that these symptoms are caused by distinct virus entities but the evidence does not indicate whether they are separate viruses or different strains of one virus.

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PHOTOSENSITIVITY DISEASES IN NEW ZEALAND

VIII. *Hypericum pulchrum* INACTIVE

By I. J. Cunningham, Animal Research Station, Department of Agriculture, Wallaceville

(Received for publication, 10 November 1955)

Summary

Powdered leaf of *Hypericum pulchrum* administered to a sheep in water suspension did not cause photosensitivity.

In a previous paper[1] photosenitization by members of the genus *Hypericum* was discussed. At that time only two species, *H. perforatum* and *H. androsaemum,* were available for study, and of these the first was found to be photosensitizing and the second not. Recently the appearance of *H. pulchrum* in the southern Wairarapa was reported to the writer by Mr. A. J. Healy, Botany Division, Department of Scientific and Industrial Research. Sufficient of this plant was collected for tests of its photosensitizing effect on sheep and it is felt worth while to report the results.

The plant was collected in February 1953, dried, and leaf and stalk separated before grinding. The procedure was therefore the same as that employed with *H. perforatum.*

Tests on sheep were carried out after the powder had been stored for approximately 24 months, and there was sufficient material for treatment of only one animal. This animal, which weighed 57 lb., was closely shorn and kept with a similar control animal, body weight 46 lb., in a paddock which provided no shade. The experimental animal was given by stomach tube 6 doses each of 300 g. powdered *H. pulchrum* leaf suspended in water on 15, 16, 17, 21, 22, and 23 February 1955. There was very little bright sunshine from 15 to 18 February, but for the 5 days from 19th, the hours of sunshine recorded were 7.6, 4.7, 9.8, 11.3, 11.4. There was occasional sunshine 24 to 27 February, and 9 hours bright sunshine on 28 February, after which the experiment was terminated.

Observations were made of ear thickness, other physical signs of oedema, sensitivity to touch, and signs of irritation in sunlight.

There was no reaction in the experimental animal to indicate photosensitivity of any degree. The experimental animal was duller than the control and did not eat well. Its body weight on 28 February was 48 lb., a loss of 11 lb., while the control weighed 49 lb., a gain of 3 lb. from 15 February.

There was a red stain on the crutch and around the prepuce which apparently derived from the *Hypericum* but the absence of photosensitivity indicated that this was not hypericin. Further, chemical examination of the leaf for hypericin by Mr. N. T. Clare, Ruakura Animal Research Station, gave negative results.

As previously reported, sheep of body weight about 90 lb. given one dose of 300 g. dried *H. perforatum* became photosensitive within 24 hours and after 3 successive daily doses were affected to a marked degree. In the present work, longer treatment with *H. pulchrum* and higher dose on a body weight basis produced no photosensitization. It seems reasonable, therefore, to conclude that *H. pulchrum* grown in the Wairarapa is not photosensitizing.

Reference

1. Cunningham, I. J. 1947: *N.Z. J. Sci. Tech. 29:* 207-13.

THE DEVELOPMENTAL ANATOMY OF PERENNIAL RYEGRASS (*Lolium perenne* L.)

By KATHLEEN SOPER and K. J. MITCHELL, Grasslands Division, Department of Scientific and Industrial Research, Palmerston North.

(Received for publication, 28 October 1955)

Summary

A description is given of the young vegetative plant of *Lolium perenne* grown in full daylight at a mean temperature of 58°F., i.e., in average New Zealand autumn conditions.

The anatomical structure of the leaf, the dimensions of the blade, the proportions of the various tissues in the blade, and the dimensions of the cells of the blade are described. The cross-sectional area of the leaf blade consists of 32% epidermal and supporting tissue, 65% mesophyll and 3% vascular tissue.

The development of the leaf was studied from its initiation as a bulge on the side of the apex to maturity.

The stem from which all leaves, tillers, and roots originate is about 2 mm. high and 2.8 mm. in diameter. It is set close to the soil surface and the environmental conditions at that level probably have considerable influence on the activity of the meristems.

The vascular systems of the leaf and stem are described and discussed in relation to the movements of nutrients and water through the plant. The importance of undifferentiated and of non-vascular tissues in conduction is emphasized.

The effects of environment on tillering and the formation of nodal roots are described. Under conditions of 20% daylight at 75°F. elongation of axillary buds to tillers is inhibited and nodal roots are small and poorly developed.

INTRODUCTION

Although a considerable amount of work has been done on the general anatomy of grasses, little is known of the detailed anatomy of the species that are of major importance in New Zealand pastures. Also, little attention has been given to the anatomical changes that must accompany the marked changes in morphology induced by variations in light intensity and temperature (Mitchell, 1953a). An anatomical examination has therefore been made of the leaves, stem, and roots of *Lolium perenne,* strain "New Zealand perennial", grown under contrasting environmental conditions, and a study made of the mode of development of the vegetative plant.

This paper describes the anatomy of the vegetative organs of plants grown in full daylight at a mean temperature of 58°F. It also describes the effects of contrasting environmental conditions, that is, of a combination of shading and higher temperature, on the anatomy of the stem and root and on the development of tillers. Accompanying changes in the anatomy of the leaf and meristematic zone from which it develops will be reported in a later paper.

Comparisons were made with "short-rotation", a strain derived from crosses of *L. perenne* and *L. multiflorum* (Corkill, 1949). Under the conditions of growth considered here, the internal structure of leaves of young plants was similar for the two ryegrasses; data are therefore presented for perennial ryegrass only.

MATERIAL AND METHODS

Plants were grown from germination either in full autumn daylight at a mean temperature of 58°F., or shaded to 20% daylight in a heated glasshouse at a mean temperature of 75°F. When the fifth leaf on the main stem had appeared, plants in each set of conditions were divided into three groups: one group was harvested for anatomical examination, a second transferred to the contrasting conditions, and the third continued under previous conditions. When the eighth leaf on the main stem had appeared all plants in the second and third groups were harvested for examination of leaf 6 on the main stem and of the stem apical zone.

Roots were collected from plants of both ages.

Material was fixed in formacetic alcohol, a mixture of 5 ml. formalin, 5 ml. acetic acid, and 90 ml. 95% ethyl alcohol. After fixation, the material was dehydrated and embedded in paraffin wax by the tertiary butyl alcohol method. Although modifications of the form-acetic alcohol and other fixatives were tried, there was always some buckling of the lateral walls of mature epidermal cells, a problem frequently met in handling this material. There was no visible distortion of the meristematic or enlarging cells.

Sections, usually 8 to 10 μ thick, were stained as follows: mature leaves in safranin, roots in safranin and light green, and apices and meristematic tissues in tannic acid and iron alum with safranin and orange G (Sharman, 1943).

Measurements of cell and tissue dimensions were taken, either direct from the sections with an eyepiece micrometer, or from outline drawings made with the aid of a micro-projector. The dimensions of cells in the lower epidermis were obtained from strips of epidermis from the base, centre, and tip of the leaf blade.

Many of the drawings are exact representations of actual sections, made by pencilling in cell outlines on photomicrographs printed on matt paper. The photograph was then bleached and the pencil lines re-drawn in ink. The diagrammatic drawings were made with the aid of a micro-projector.

STRUCTURE OF THE RYEGRASS PLANT

Fig. 1 is a drawing of a young plant grown outside in full daylight, presented to show the relative positions and proportions of organs of a young plant.

In this particular plant there are three mature leaves with blades of lengths 3.4, 4.8, and 5.2 cm. respectively, and sheaths 1.0 to 1.5 cm. in length. The older sheaths encircle the younger ones. A fourth leaf has emerged above the sheaths of the older leaves but has not yet attained full length. The stem itself is situated at the centre of the bases of the leaf sheaths. It consists of a crown of solid material upon which the leaves and stem apex are borne. Tillers are shown arising from the axils of the coleoptile and the first leaf. The coleoptile tiller frequently fails to develop.

Emerging from the base of the stem through the leaf sheaths are 10 adventitious roots. These are white and relatively thick, about

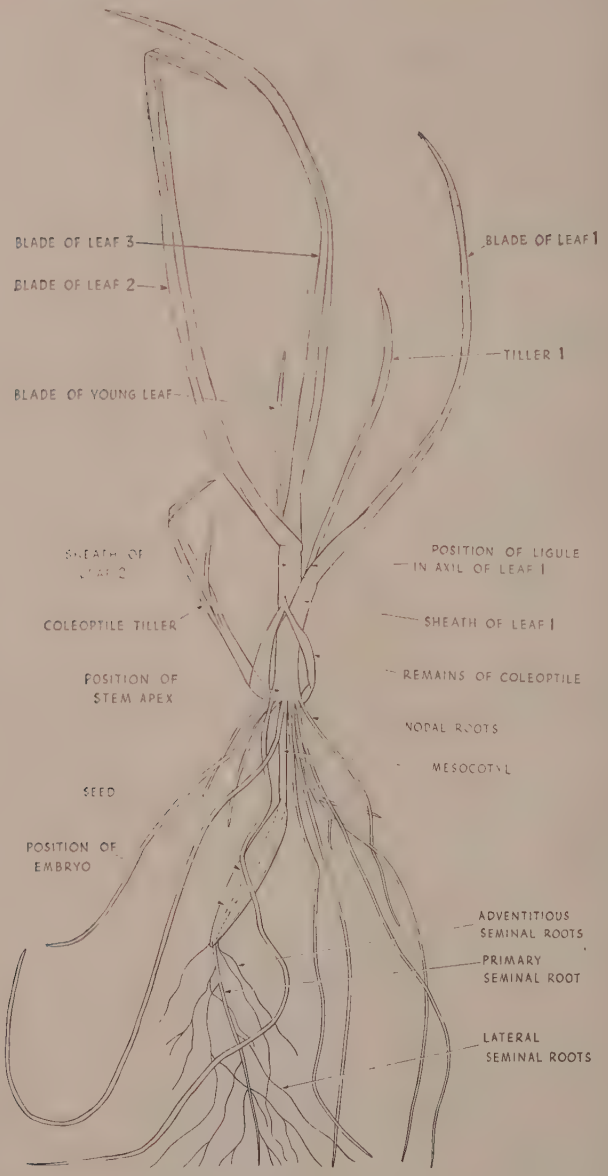

Fig. 1.—Young plant of perennial ryegrass grown in full daylight at 58°F. (× 1¾.)

0.7 mm. in diameter. Although they originate from successive stem nodes they emerge close together, since there is little elongation of the internodes, except for the mesocotyl (see below). This contrasts with *Zea mays* (Sharman, 1942) in which the internodes do elongate and

a distinct ring of adventitious roots emerge from each of the lower nodes.

In plants grown under shading and high temperature, the leaves were much longer and narrower, there was little tiller development, and the nodal roots were thin and thread-like.

Quite separate from the nodal roots are the seminal roots, which emerge from the base of the embryo. There is often only one primary seminal root which bears numerous lateral branches. Alternatively, adventitious roots may start development in the embryo so that the embryo possesses two or more root primordia in the hypocotyl in addition

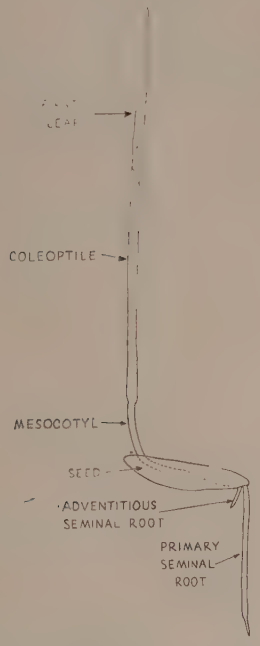

Fig. 2.—Seedling of perennial ryegrass showing the position of the elongated mesocotyl between the coleoptile node and the seminal roots. ($\times 2\frac{1}{2}$.)

to the terminal radicle. All these are "seminal" roots. (Esau, 1953 p. 473).

The mesocotyl, which is the first internode of the seedling, elongates upon germination and carries the stem bud and surrounding coleoptile up to the soil surface, separating them from the seminal roots and from the scutellum (or cotyledon) which remains within the seed (Fig. 2).

Fig. 3 shows diagrammatically median longitudinal sections through the bases of the shoots of plants grown in full daylight at 58°F. and in 20% daylight at 75°F., and Fig. 4 shows cross-sections through the same shoots at the level of the main stem apex. The sequence of development of leaves, buds, and roots can be seen, as well as the differences resulting from the contrasting environmental conditions,

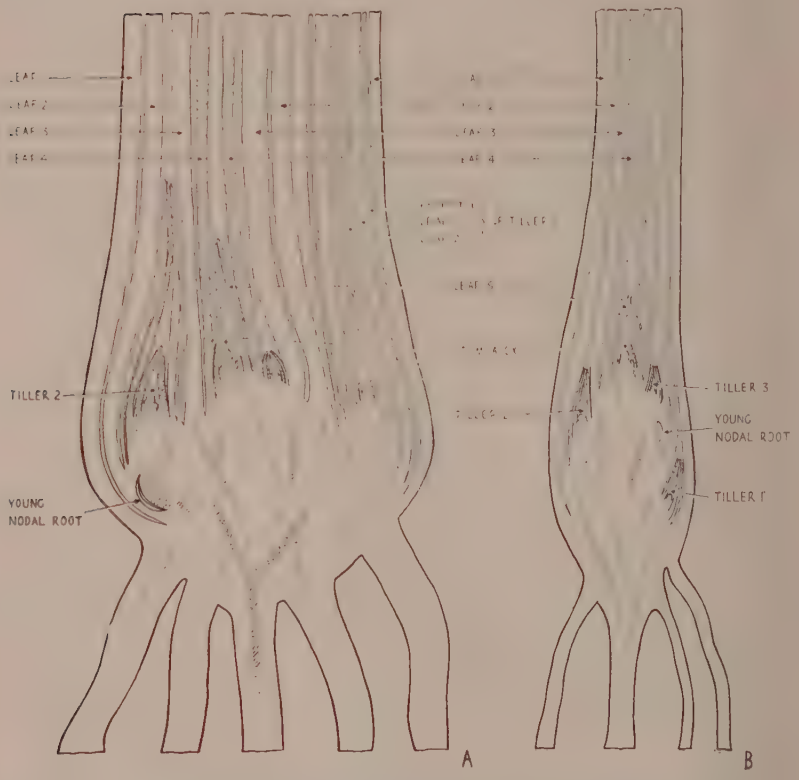

Fig. 3.—Diagrammatic median longitudinal sections through the stem region of young plants grown (A) in full daylight at 58°F. and (B) in 20% daylight at 75°F. Meristematic and vascular tissue stippled. (× 16.)

Fig. 3A includes about 5 mm. of the plant above the soil surface. It shows the dome-shaped apex bearing three or four leaf primordia and surrounded by two developing leaves and the sheaths of three mature leaves. The immature fourth leaf has emerged a few cm. above the sheaths of the older leaves (Fig. 1). The tissue of this emerged portion is mature. The lower portion of the leaf is still enclosed by the sheaths of older leaves. The cells at its base are completely meristematic (Fig. 3A) and there is a gradual change from meristematic tissue at the base to mature tissue at the point of emergence. The fifth leaf is 1 mm. in length and wholly meristematic. Fig. 3B is a comparable section through a plant grown in shade at 75°F. The leaves of this plant are only half as thick as those grown in full daylight at 58°F.

In the plant grown in full daylight at 58°F. tillers are visible soon after the first two or three leaves have matured (Fig. 1). The first tiller, that in the axil of the first leaf, has emerged above the leaf sheath (Fig. 1) and the development of an axillary bud from the tiller itself has already commenced (Fig. 4A). Leaves of the second tiller are elongating (Fig. 3A) but have not yet emerged. The third tiller is still

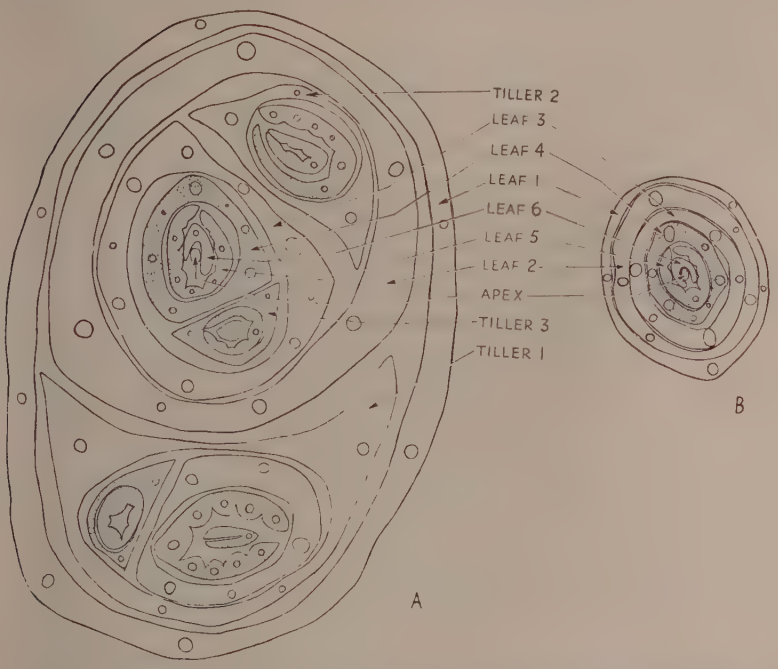

Fig. 4.—Transverse sections at the level of the top of the apex of the main stem. These are from plants grown (A) in full daylight at 58°F. and (B) in 20% daylight at 75°F. Meristematic tissue stippled. (× 30.)

a bud (Fig. 3A) with its prophyll (the pre-leaf of the tiller, homologous to the coleoptile of the seedling) together with the first leaf within it, forming a hood over the bud apex.

It has been shown that shading at high temperature will inhibit development of axillary buds (Mitchell, 1953b) and it can be seen from Fig. 3B, in contrast with Fig. 3A, that although plants grown under these conditions form buds in normal sequence, no leaves have developed sufficiently to extend beyond the tip of the apex of the main stem. This can also be seen from Fig. 4B which shows a section taken at the level of the top of the apex.

The stem apex and subapical meristematic region bearing developing leaves form a meristematic cap beneath which the stem widens rapidly. In the plant grown in full daylight at 58°F., the stem apex and supporting column of meristematic tissue bearing the unelongated leaf primordia is only 0.2 mm. high, and 0.13 mm. wide at the base. The entire stem is only 2.0 mm. from tip to base and 2.8 mm. across at the widest point. Shading and higher temperature have little effect on the size of the apex itself but there is considerable elongation and narrowing of the stem as a whole (Fig. 3B). The stem base is slightly longer (2.4 mm.) and much narrower (1.3 mm.).

The association between the formation of axillary buds and the initiation of nodal roots is shown in Figs. 3A and B. Up to four nodal

roots develop within the stem opposite the base of the leaf in whose axil the young tiller bud has appeared, and grow out through the bases of this and surrounding leaf sheaths. Inhibition of the axillary buds, by shading at 75°F., does not prevent development of adventitious roots from the node at the base of each leaf. However, fewer roots develop and they are thin and thread-like.

Structure of the Leaf

The blade consists of a skeleton of parallel vascular bundles which, together with the epidermis and sclerenchymal strands, support the mesophyll. Besides a large median vein, there are two or more lateral veins with a varying number of smaller veins between them (Figs. 5A and B). The veins show a structure typical of monocotyledons (Fig. 6). The larger veins have vessels in the xylem and sieve tubes in the phloem. In the smaller veins there are only tracheids in the xylem and parenchyma in the phloem (Fig. 6). These are characteristic differences between large and small veins in leaves of many species.

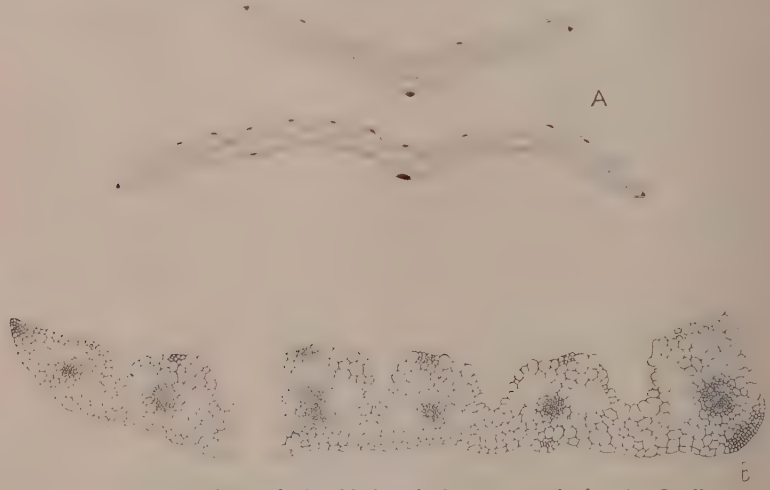

Fig. 5.—Transections of the blade of the mature leaf. A. Outline diagrams of leaf two and leaf six on the main stem showing differences in size between the two leaves. (× 25.) B. Portions of the leaf on a larger scale (× 80) including the median vascular bundle, lateral bundles of varying sizes, and the small bundle at the edge of the leaf.

Sub-epidermal strands of sclerenchyma occur below the median vein, usually above each vein and sometimes below the lateral veins (Fig. 5). There is also a strand along each edge of the leaf. Surrounding the vascular bundles are two layers of cells (Figs. 5B and 6). The inner sheath is of thick-walled, more or less lignified cells with the thickening heaviest on the radial and inner tangential walls. This layer probably serves as protection against crushing of the phloem cells and adds rigidity to the leaf as a whole. The outer sheath is of thin-walled parenchyma cells which contain small numbers of chloroplasts. On the phloem side of the bundle the cells of the sheath are indistinguishable from other mesophyll cells in the number of chloroplasts that they

Fig. 6.—Transverse sections of vascular bundles in the leaf. The large bundle contains xylem vessels and sieve tubes but the small bundle has only tracheids and phloem parenchyma. (× 340.)

contain. There is often an extension of the bundle sheath above the main vein and sometimes above the lateral veins, which either terminates in the mesophyll or reaches the epidermis (Fig. 5).

Generally there is only spongy mesophyll in the leaf blade, though sometimes there is a weakly-developed palisade layer on one or both sides of the blade (Figs. 5 and 12). Intercellular spaces are abundant.

The cells of both the upper and lower epidermis are elongate-rectangular in surface view (Fig. 7). At the bottom of grooves in the upper surface of the leaf are the larger, thin-walled, bulliform cells. Stomata are present on the upper surface only of the leaf, usually on the sides of the ridges (Figs. 5 and 7).

The base of the leaf forms a sheath around the stem and younger leaves. The top of the sheath and the base of the blade are separated by a band of tissue in which the epidermal cells are much shorter and the mesophyll cells of the leaf are replaced by closely-packed, relatively thick-walled parenchyma cells (Fig. 8). The ligule, which originates as a fold of the upper epidermis (Sharman, 1941) projects upward from the inner side of this band, as a thin membranous structure.

There are several differences between the blade and the sheath (Figs. 5 and 9). The blade is flattened while the sheath is tubular. The inner surface of the sheath is not ridged as is the upper surface of the blade. In the sheath there is little photosynthetic tissue, and that is confined to the upper and outer part (Fig. 8), but may sometimes extend down round the vascular bundles. Elsewhere, its place is taken by thin-walled, colourless parenchyma cells. Through the breakdown of this parenchymatous tissue large spaces are formed within the mature leaf sheath.

There are often fewer vascular bundles in the sheath than in the blade. Some of the smaller bundles terminate in the ligular region and

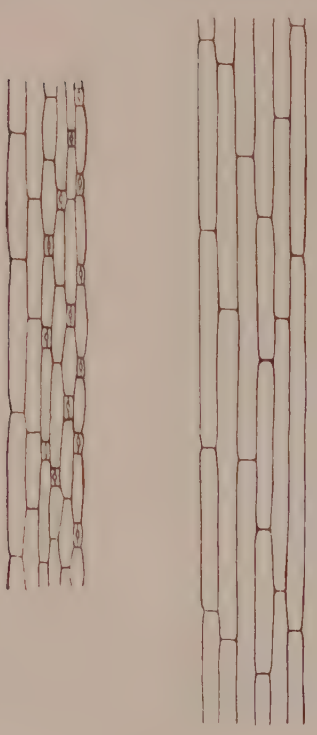

Fig. 7

Fig. 8

Fig. 7.—Epidermal cells in surface view. On left, tissue from the side of a ridge showing the stomata and adjacent rows of bulliform cells. On right, the lower epidermis with much larger cells and no stomata. (× 90.)

Fig. 8.—Longitudinal section through the ligular region of the leaf. The blade and outer portion of the sheath contain photosynthetic tissue (stippled). (× 116.)

others merge with larger bundles in the sheath (Fig. 10) which continue down into the stem. Throughout the sheath the longitudinal bundles are laterally interconnected by transverse strands. These also occur in the blade, but are few and inconspicuous.

Dimensions of the Leaf Blade and Cells, and Tissue Proportions

Table 1 records the dimensions of the blades of leaf 2 and leaf 6 on the main stem of plants grown in full daylight at 58°F. Table 2 records the proportions of the different tissues present as estimated from the cross-sectional area at the base of the blade. Although the blades differ in size, tissue proportions are the same. Noteworthy features are the high percentage of epidermis and the very low percentage of vascular and sclerenchymatous tissue. Mesophyll occupies more than half the total cross-sectional area of the blade. Of this about a tenth is bundle sheath tissue and a considerable proportion is intercellular space. The exact proportion of the latter is difficult to measure from sectioned material.

Fig. 9.—Transections of the leaf sheath. Above, an outline diagram of the whole sheath (× 25) and below, a portion of the sheath enlarged (× 80) to show the manner in which vascular bundles are embedded in parenchymatous tissue.

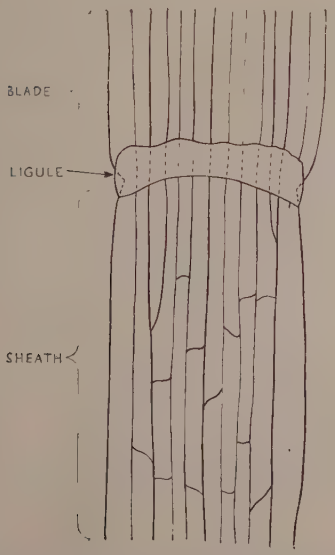

Fig. 10.—Diagram of the vascular system at the base of the leaf blade and the top of the sheath. The majority of bundles are common to both blade and sheath, but one smaller bundle terminates at the ligule position and two others merge with large bundles in the sheath. (× 10.)

TABLE 1. DIMENSIONS OF LEAF BLADE OF PERENNIAL RYEGRASS GROWN IN FULL DAYLIGHT AT 58°F.

Means and Standard Deviations given for 6 Leaves

	Length (cm.)	Width at Base (cm.)	Area of Blade (sq. cm.)	Thickness at Base (cm.)*	Cross-Sectional Area at Base (sq. cm.)	No. of Vascular Bundles
Leaf 2	6.4 ± 0.3	0.31 ± 0.02	1.39	0.023 ± 0.003	0.0059 ± 0.0007	8 ± 1
Leaf 6	10.7 ± 1.5	0.45 ± 0.06	3.69	0.025 ± 0.004	0.0089 ± 0.0010	15 ± 2

*Measured through largest lateral vein.

TABLE 2. PROPORTIONS OF TISSUES IN LEAF BLADE (PERCENTAGES OF CROSS-SECTIONAL AREA OCCUPIED)

Means, and in most cases Standard Deviations, given for 6 Leaves.

	Epidermis	Mesophyll (excluding Sheath)	Outer Bundle Sheath	Mesophyll (including Sheath)	Vascular Tissue	Sclerenchyma
Leaf 2	32.2 ± 0.8	59.2	4.1	63.5 ± 0.7	3.3 ± 0.5	0.7 ± 0.2
Leaf 6	29.0 ± 4.0	60.5	5.2	65.7 ± 4.0	3.7 ± 0.3	1.7 ± 0.9

The dimensions and numbers of the various types of cells in the blade of leaf 2 and leaf 6 are recorded in Tables 3, 4, and 5. There are no marked differences in average size between cells of the lower epidermis in the two leaves. They average nearly 0.5 mm. in length but are only about 0.02 mm. in width. In leaf 2 there are no significant differences in average width or length of these cells along the blade but in the blade of leaf 6 both width and length decrease toward the tip.

Cells in the upper epidermis vary in shape (Fig. 7). Those at the top of the leaf ridges are of similar depth and width to those of the lower epidermis but only about half the length.

TABLE 3. VARIATIONS IN DIMENSIONS OF CELLS OF LOWER EPIDERMIS ALONG THE LEAF

Means and Standard Deviations given for 60 Cells

	Leaf 2			Leaf 6		
	Base	Centre	Tip	Base	Centre	Tip
Length (μ)	455 ± 135	474 ± 120	434 ± 116	518 ± 156	475 ± 108	430 ± 114
Width (μ)	23 ± 4	19 ± 3	20 ± 9	24 ± 5	20 ± 3	17 ± 3
Depth (μ)	30 ± 6			25 ± 8		

TABLE 4. NUMBERS OF LOWER EPIDERMAL CELLS IN LEAF BLADE

	Number across Base	Estimated Number along Leaf	Estimated Total Number of Cells
Leaf 2	135	141	16,300
Leaf 6	188	226	36,300

TABLE 5. DIMENSIONS OF CELLS IN LEAF BLADE (μ)
Means and Standard Deviations given. n in brackets

	Mesophyll Cells			Vessel Length (30)	Outer Bundle Sheath Cell Length (120)
	Length (240)	Width (60)	Depth (60)		
Leaf 2	23 ± 4	24 ± 4	34 ± 5	463 ± 120	60 ± 15

In the vascular bundles the vessels are of similar length to the cells of the lower epidermis. The bundle sheath cells are isodiametric in cross-section and about one-eighth the length of the vessels. Mesophyll cells in the layer adjacent to the epidermis show some elongation in a direction at right angles to the leaf surface. Cells of the inner mesophyll are also usually elongated in this direction but are more irregular in shape.

Stem Apex and Meristematic Regions

The structure of the stem apex and leaf primordia may be seen from Fig. 11. The detailed structure of the apex and the initiation and development of the leaf primordia in the Gramineae have been described by several investigators including Sharman (1945) and Esau (1953) and will not be repeated here.

TABLE 6. DIMENSIONS OF STEM APEX
Means and Standard Deviations given for Diameters of 6 Apices

Number of Leaves on Main Stem	Diameter (mm.)	Circumference (mm.)	Cross-Sectional Area (sq. mm.)	Mean Width of Cells (μ)	Mean Height of Cells (μ)	Number of Cells across Diameter	Number of Cells from Tip to Point of Measurement
5	0.072 ± .014	0.226	0.0041	8.0	7.2	8–10	4–6
8	0.080 ± .008	0.251	0.0050	8.0	8.0	9–11	5–6

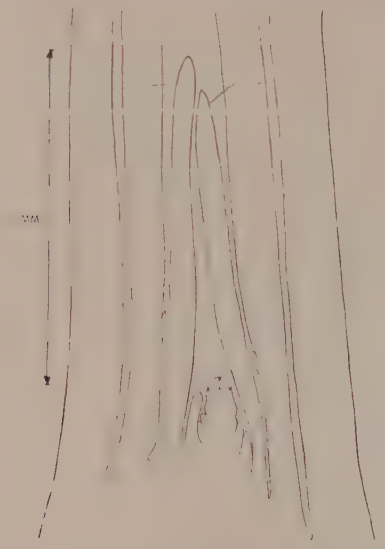

Fig. 11.—Diagrammatic median longitudinal section through the stem apex and surrounding leaves showing the points at which measurements of the dimensions of the apex were made. (× 50.)

Measurements of the dimensions of the apex were taken at a point whose distance from the tip of the apex was equal to the horizontal radius (Fig. 11). The measurements presented in Table 6 were taken from plants grown in full daylight at 58°F. In the first group the fifth leaf had just emerged from the surrounding leaf sheaths, and in the second group the eighth leaf had just emerged. The size of the stem apex and the number and size of the cells in it had not increased to any extent in the older plants. The data show an increase of about 10% in the circumference of the apex but this does not reach significance at the 5% level of probability.

Each leaf primordium appears as a small protuberance on the side of the apex a short distance below its tip. This rapidly extends laterally to form a collar round the apex. At the same time the tip of the leaf where the initial cell divisions occur grows upwards, so that by combined apical and marginal growth of the primordium a hood is formed over the apex. This apical and marginal growth lasts a short time, after which intercalary growth at the base of the primordium continues the process of elongation of the leaf up within the sheaths of the older leaves.

At first the intercalary meristem at the base of the primordium consists entirely of small, rapidly dividing cells which are densely protoplasmic with large nuclei and are arranged in columns. As the leaf elongates, cell division gradually becomes confined to the base of the leaf, while higher up it is replaced by cell elongation and maturation and the formation of intercellular spaces in the mesophyll (Figs. 12 and 13).

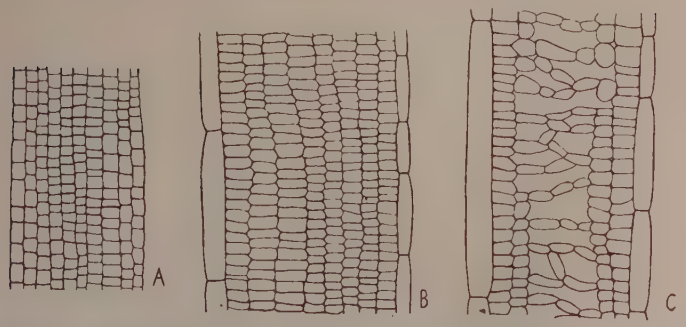

Fig. 12.—Longitudinal sections of the developing leaf taken (A) just above the ligule when that was 0.1 mm. above the stem apex; (B) just below the point of formation of intercellular spaces; (C) a short distance above the level where formation of intercellular spaces began. Lower surface on left hand side in each section. (All × 150.)

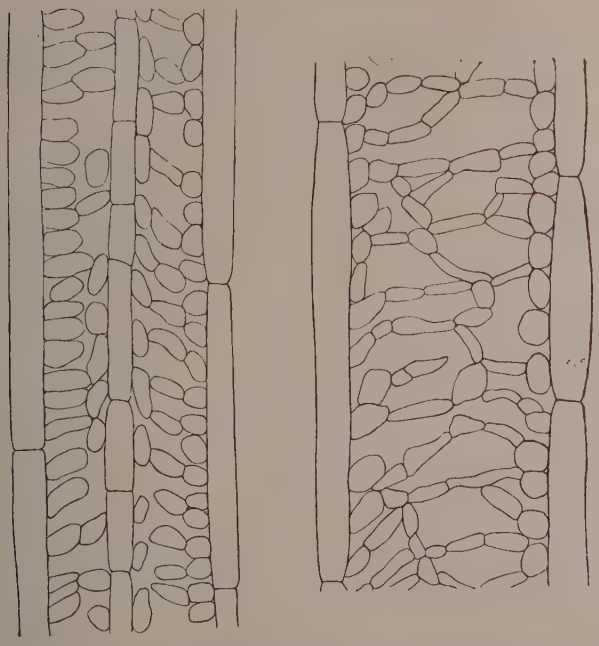

Fig. 13.—Longitudinal sections of a mature leaf showing on right the horizontal elongation of the mesophyll cells in between the vascular bundles and on left a section through the edge of a vascular bundle showing the elongated bundle sheath cells. Lower surface on left in each section. (× 150.)

Cell elongation begins first in the lower epidermis of the leaf blade near the base of the intercalary meristem and continues in that tissue for about 10 to 12 mm. up the leaf. Mature cells in the lower epidermis are about thirty times their original length and two to three times their

original width. As cells of the upper epidermis are, at maturity, about half the length of those in the lower epidermis, cell division must continue for a longer period in the upper than in the lower epidermis.

At first, epidermal and mesophyll cells are of the same size and shape. Cell division continues in the mesophyll after the epidermal cells have commenced to elongate. A phase of very active cell division occurs in the mesophyll at about the level of the top of the stem apex. As a result, the length of these cells along the leaf actually decreases at a position where the average length of adjacent cells in the epidermis is increasing. Hence there is a continual increase up the leaf in the number of mesophyll cells adjacent to each epidermal cell. By the time cells of the epidermis have attained their final length, there are up to 20 mesophyll cells to each lower epidermal cell. MacDaniels and Cowart (1944) found a ratio of between 8 and 10 palisade cells to each cell of the upper epidermis in the apple leaf.

The formation of intercellular spaces in the mesophyll has been described by MacDaniels and Cowart (1944) and Avery (1933). Elongation of the epidermal tissue continues after cell division has ceased in the mesophyll and is a factor in the pulling apart of the mesophyll cells. The appearance of intercellular spaces occurs first in the central mesophyll; this may be due to the earlier cessation of cell division in this tissue.

In the early stages of development of the leaf there is no differentiation between blade and sheath. After the leaf has grown 1 cm. or more in length, the ligule and the band of specialized tissue across the leaf develop near the base of the leaf and the intercalary meristem becomes divided into two parts, the upper completing the growth of the blade and the lower being responsible for the growth of the sheath. The base of the sheath is the last part of the leaf to mature.

Vascularization in the Developing Leaf

The origin of the leaf traces was not investigated in detail. It appears to accord with Sharman's description (1942). Cell division marking the initiation of the median bundle in the leaf blade occurs first in the axis below the leaf primordium and extends up into the primordium. The first lateral bundles arise near the junction of the leaf base and stem and differentiate up into the leaf and down into the stem. Later, smaller intermediate bundles arise in the intercalary meristem near the tip of the leaf and develop downwards as the leaf matures. The later-formed bundles are progressively smaller and less well differentiated.

The sequence of appearance of vascular strands is shown in Fig. 14. The stages shown in the cross sections may be taken as representative of successive stages in the growth of the leaf, since it is being built up from below and the oldest part is at the tip. Near the tip of the blade, only the median and two lateral bundles are present. Lower down the leaf small intermediate veins arise as the width of the leaf is increased by lateral cell division. These veins appear to arise *de novo* as space becomes available. The formation of new intermediate veins occurs only while the leaf is increasing rapidly in width, that is, during the initial period of apical and marginal growth of the primordium before cell division becomes restricted to the intercalary meristem at the base

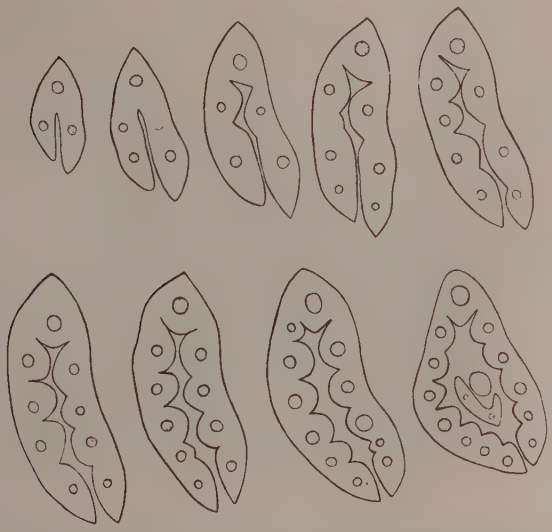

Fig. 14.—Transections taken at intervals down a young leaf 2 mm. long, illustrating the course of initiation of vascular bundles in the leaf blade. The median and first-formed lateral veins are stippled. (× 55.)

Fig. 15.—From left to right, transections taken at intervals down a young leaf 2 mm. long showing the initiation of a new vascular bundle. Cell divisions starting from a central cell lead to the organization of a new bundle in the space between two existing bundles. (× 240.)

of the leaf. Thus in the fully elongated leaf blade it is only toward the tip that there are fewer veins.

The mode of initiation of an intermediate bundle is shown in Fig. 15. Between the earlier-formed bundles the leaf is usually five cells deep. A central cell in the middle layer divides and, by repeated longitudinal division of this and adjacent cells, a new bundle is formed. This results in the formation of a ridge on the upper surface of the leaf.

As the differentiation of the vascular system of leaves has been examined by a number of investigators, including Avery (1933), Sharman (1942), and Esau (1954), it will not be described in detail here. Associated with the differentiation of the vascular tissue itself is the differentiation of the sheath cells around the bundles and fibre strands above and below the larger bundles.

In the stem, the vascular bundles form a complex network of anastomosing strands. The earlier-initiated median and lateral bundles of the leaf arise when the leaf primordium is small and hence are placed close to the centre of the axis. As the leaf matures, they anastomose with bundles from other leaves. The later-formed bundles, which arise when the leaf primordium has grown further out from the stem, occupy positions progressively nearer the periphery. Some of these small bundles appear to terminate in the ground parenchyma without connecting with the vascular network of the stem.

While much of the vascular tissue in the stem consists of highly specialized conducting elements, much is in a relatively rudimentary state of differentiation. The whole is closely intermingled with parenchyma.

Root Anatomy

Fig. 16A shows a transverse section of a nodal root from a plant grown at 58°F. in full daylight, and Fig. 17 shows a part of it in detail.

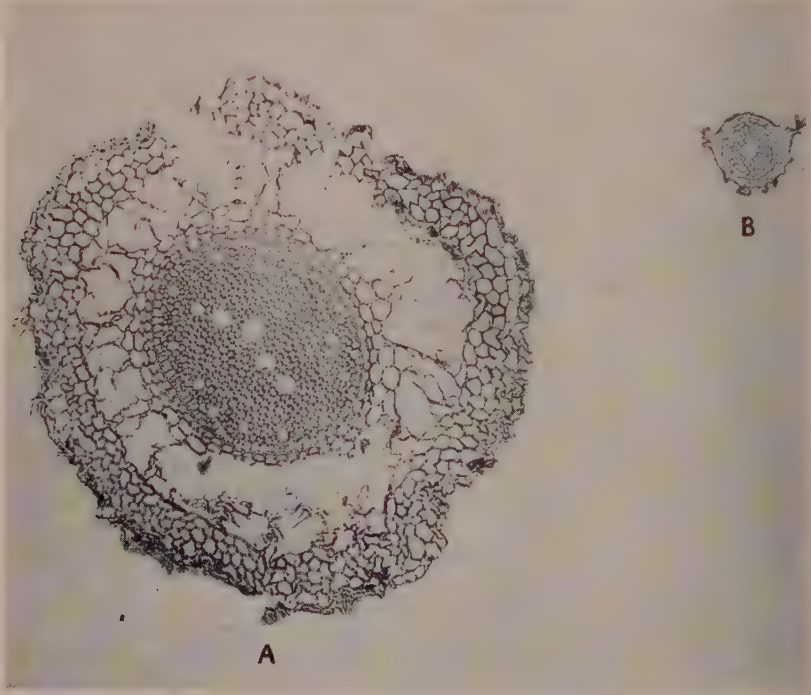

Fig. 16.—Photomicrographs of transections of nodal roots of plant grown (A) in full daylight at 58°F.; (B) in 20% daylight at 75°F. (× 90.)

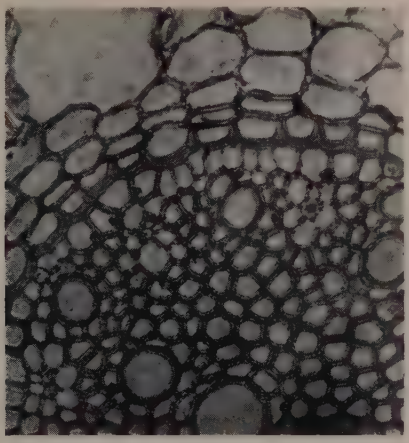

Fig. 17.—Enlargement of a section of root in Fig. 16A to show details of stelar structure. (× 360.)

The structure of the root is similar to that of a typical monocotyledon. On the outside there is the piliferous layer with its root hairs, within that the ill-defined exodermis, then the wide cortex with its inner portion lacunate. The lacunae may be either schizogenous, or lysigenous. The endodermis on the inner margin of the cortex has its radial and inner tangential walls thickened. Within the endodermis is a one-layered pericycle. In the root illustrated, there are thirteen protoxylem groups alternating with phloem groups round the periphery of the stele and five metaxylem vessels in the centre of the stele separated from each other and from the peripheral xylem by sclerified parenchyma. Generally, in nodal roots of plants grown under these conditions there are ten or more protoxylem groups and often less than five central metaxylem vessels.

Nodal roots from plants grown in the shade at 75°F. are smaller in diameter (Table 7). The stele is small and usually has only one central metaxylem vessel and six or seven protoxylem groups (Fig. 16B). The cortex is often not more than one or two cells thick.

TABLE 7. DIMENSIONS OF CROSS-SECTIONS OF NODAL ROOTS

Means and Standard Deviations given for 6 Roots

Treatment	Diameter of Whole Root (mm.)	Width of Cortex (mm.)	Diameter of Stele (mm.)
Full Daylight 58°F.	0.76 ± 0.17	0.22 ± .08	0.32 ± 0.01
Shaded to 20% Daylight 75°F.	0.15 ± 0.03	0.03 ± 0.007	0.10 ± 0.02

The transference of plants from full daylight at 58°F. to 20% daylight at 75°F. resulted in a reduction in diameter and a browning of the existing nodal roots. This was due to a breakdown of the cortex. Jacques (1941) also found that roots that have originally developed a wide cortex can lose it when growth conditions become unfavourable.

Discussion

The Effects of Environment on Vegetative Growth

A feature of the vegetative growth of ryegrass is that the major part of the growth and development of leaves and tillers occurs in the very small volume of meristematic tissue at the top of the stem. This includes the stem and tiller apices, their subapical regions where the leaf primordia are borne, and the meristematic bases of the immature leaves surrounding them. In the plant pictured in Fig. 3A this meristematic tissue has a volume of approximately 0.8 cu. mm., excluding the upper parts of the leaves where cell elongation is still taking place but cell division has ceased. This meristematic zone is situated close to the soil surface and is subject to the environmental conditions at that level. Under pasture, these can be quite different from conditions at other levels in the pasture or in the surrounding atmosphere. For example, Mitchell (1955) has shown that, in summer, the surface temperature of soil under pasture may be 40°–50°F. higher than the air temperature as measured in the standard Stevenson screen at 4 ft. above the soil surface. Under these circumstances the temperatures at which the meristematic zone is functioning may be much higher than standard air temperature.

The importance of environmental conditions is well illustrated by the effect of shading at high temperatures on tillering.

Tillering, as a means of increasing the size of the vegetative plant, is of considerable importance in many of the Gramineae. As each tiller grows out from the axil of a leaf on the parent stem it develops in turn its own leaves and roots, and thus becomes potentially independent of the parent. An essential part of tillering is its close association with the formation of nodal roots. The initiation of the axillary bud from which the tiller develops occurs just prior to the initiation of the primordia of the roots. This happens irrespective of environmental conditions. The latter, however, do affect subsequent development. Shading at high temperatures retards the development of both tillers and roots, but has a greater inhibitory effect on the tillers.

This effect is not unexpected. In the vegetative plant food is used firstly for maintenance and secondly for growth. Any surplus is stored, for example, in the root cortex. Shading reduces the amount of carbohydrate formed by the plant, while high temperatures, by increasing the metabolic rate, increase the demand. The combination of shading and high temperatures will therefore place a considerable strain on the food resources of the plant. Maintenance and growth of the main stem have priority over the formation of new growth centres for such food as is available (Mitchell, 1953b). Consequently, the development of axillary buds to tillers is inhibited.

The growth of the roots will also be limited, since they are dependent on the shoot for their carbohydrate supplies. Not only is

less carbohydrate formed and more used by the shoot, but also the translocation of sugars from the leaves may be decreased at the higher temperature, as in the tomato (Went, 1944). The roots may therefore be developing under conditions of acute carbohydrate deficiency with the result that the stele is small with few conducting elements and the cortex poorly developed. The conducting and storage capacities of these roots will be greatly reduced.

The effect of environment on root efficiency is further illustrated by the transfer of plants from full light at 58°F. to shade at 75°F., which resulted in the breakdown of the wide cortex developed under the favourable conditions. Root efficiency would be greatly reduced through the loss both of tissues which serve for storage and "free space" conduction (Butler, 1953) and of the piliferous layer with its root hairs.

Knowledge of the development of the stem and its axillary buds may assist in explaining the poor response of inhibited buds to a change to more favourable conditions. The older the bud the more difficult it is to stimulate it to resume development (Mitchell, 1953b). There are two possible reasons for this. One is that there is a progressive loss on the part of the cells of the bud of the ability to respond. No evidence for or against this was obtained in the present work. The second possibility is that while the bud is close to the stem apex where the supply of nutrients is high, it can obtain adequate food for development. With the continued growth and maturing of successive leaves, the bud becomes progressively more isolated from the main meristematic zone and from the food supply since most of the latter will go by way of mature vascular strands to the surrounding leaves and stem.

Conduction of Nutrients and Water through the Stem

Within the small and compact stem the vascular system is a complex network of strands from the leaves and roots. Its component cells are by no means homogeneous. They range from highly specialised xylem and phloem elements to meristematic cells and cells in a rudimentary state of differentiation, all intermingled with parenchyma. Further, not all the vascular strands from the leaves communicate with the stem network. Consequently, the pathways of transport of nutrients and water through the stem lie not only along specialised conducting tissues but also across tissues which are not specialised for conduction, that is, relatively undifferentiated or non-vascular tissues. Some part of the transport of nutrients and water must therefore be by diffusion or mass flow (Hylmö, 1953) through the cells of these tissues.

Conduction in the Developing Leaf

Conduction through undifferentiated tissues is important in the immature leaf also, since, before the median strand connects it with other leaves, the primordium must obtain all its food by transport across meristematic cells. As it develops and its vascular strands differentiate, the leaf will receive supplies of food in increasing quantities. Before it begins to manufacture its own carbohydrates, it will obtain the necessary organic substances from older leaves by translocation up from the stem (Mason and Maskell, 1928). When the leaf becomes exposed at its tip, the cells near the point of emergence are fully elongated and mature. Organic substances produced by photosynthesis in the exposed portion of the leaf will travel down the leaf by way of the protophloem

which differentiates very early in the median and lateral strands. At the intercalary meristem most or all of this food material will be diverted to the meristematic cells to be used in the building-up of new cells. After the leaf attains maturity and the intercalary meristem disappears, all the organic material not used in cell maintenance will be transported into the shoot.

Extra-Vascular Conduction in the Mature Leaf

Wylie (1943, 1952) has presented evidence that extra-vascular conduction occurs in the mature leaf blade. He regards the bundle sheaths and their extensions, together with the epidermis, as a supplementary conducting system. Water and solutes pass from the vascular tissues into the bundle sheaths and thence by way of the sheath extensions, where these occur, or more slowly by way of the mesophyll, to the epidermis. Here, because of the extensive lateral contact areas between the cells, water spreads readily throughout and eventually penetrates to mesophyll cells which lie at some distance from the vascular bundles.

The structure of the ryegrass leaf blade appears to be particularly favourable for extra-vascular conduction. The length of the bundle sheath cells, and particularly of the epidermal cells, will facilitate conduction along the blade. The proportion of epidermal tissue is high relative to the other tissues, owing to the thinness of the blade, and therefore no point inside the leaf is far from the epidermis. In this connection, the high proportion of the epidermal tissue compared with the very low proportion of the vascular tissue, is of interest.

Extra-vascular conduction is probably less important in the leaf sheath since in the mature sheath much of the internal parenchymal tissue, and later the epidermal tissue, breaks down. The numerous lateral connections between the parallel vascular bundles in this part of the leaf will facilitate transport by the vascular system.

In the band of tissue between the blade and the sheath the closely-packed arrangement of the parenchyma cells suggests that this structure could serve as a major junction in the transfer of solutes and water between the vascular bundles and the epidermis in this part of the leaf. Longitudinal conduction into the blade could then take place not only along the specialised vascular channels but also up through the epidermis from the base of the blade.

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MEASUREMENTS OF DISTRIBUTION OF WEEDKILLING SPRAY APPLIED TO GORSE (*Ulex europaeus*) BY HELICOPTER AND AEROPLANE

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Summary

Measurements of distribution of a spray mix based on 2,4,5-trichloroacetic acid were made by means of sensitized cards, placed in various ways within gorse, and by continuous paper strips erected clear of the gorse and about 6 ft. above ground level. For each machine (helicopter and aeroplane) the distribution across a spray swath left by a single "run", and also the effect of several overlapping "runs" in a commercial operation were measured.

The swath width from a single "run" of the helicopter was about 60 ft., and that of the aeroplane, about 110 ft. The assessed density of spray was, for the aeroplane, on the average about half that assessed for the helicopter operation, across this spray swath. The spray distribution across a single swath was more even with the helicopter, and the wind-drift of spray was considerably less. The amount of spray penetrating into the gorse bushes fell-off rapidly in the interior of the bushes, with both machines.

In droplet-size distribution, the helicopter gave a more even mixture of sizes across the swath than the aeroplane. With the aeroplane the effect of wind was more marked, most coarse drops falling more or less under the path of the machine and most fine drops being carried down wind. There was a slightly greater proportion of fine drops found within the gorse bushes than nearer the outside of the bushes.

Introduction

Few detailed measurements have been made in New Zealand of the efficiency in terms of coverage of aerial spray applications. With the recent introduction of the helicopter into the field of agricultural spraying, it was considered that an effort should be made to assess spray coverage and penetration secured from this machine as well as that from a fixed-wing aeroplane. With the assistance of Messrs. Imperial Chemical Industries (N.Z.) Ltd., a trial was therefore arranged at Whatawhata, near Hamilton, on 24 March 1955.

Overseas Investigations

Much work on measuring spray distribution has been conducted at the Personal Aircraft Research Centre College Station, Texas (Weick and Roth, 1955). This College has developed special designs of agricultural aeroplanes and has investigated nozzle arrangements under fixed-wing aircraft to give desired spray distribution patterns (Weick and Roth, 1954), and the effect of the type of spray nozzle used, of airspeed, and of spray pressure. The work has application mainly to level ground and to a short-growing crop. In the measurements to be described in this paper, nozzle spacings were uniform over the boom width for both the helicopter and the aeroplane (except under the fuselage). While this may not be the ideal spacing in the case of the aeroplane, the authors have no knowledge of the effect of nozzle groupings with the helicopter.

The results of the present trial, however, indicate that uniform spacings of nozzles do not give grossly irregular spray-distribution patterns.

Any results described in this paper have reference only to the particular type of spray equipment used in both helicopter and aeroplane. Improvements in this equipment would no doubt give a corresponding improvement in the spray-distribution patterns.

Experimental Technique

Description of Trial Area

The area chosen was covered with dense gorse varying from 4 ft. to over 8 ft. in height. Gorse of this nature was chosen, not because it was considered likely to be killed by the chemicals used, but because it offered a convenient means of securing data on the penetration of spray into dense scrubby growth. The browning of such gorse has acted as a visual broad-scale measure of the over-all efficiency of cover of the spray, and detailed spray distribution measurements were also made by means of sensitized cards placed in various ways within the gorse. The topography of the area was gently rolling, and all sprayed areas were ploughable.

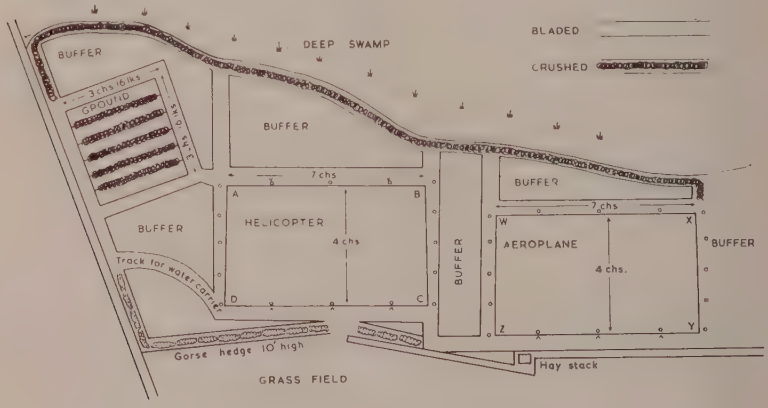

Fig. 1 —General plan of trial area.

Three areas were prepared by marking out boundaries with a bulldozer, giving easy access (Fig. 1).

Area 1: Helicopter area. This covered 2.8 acres. The ground was more uneven than that for the aeroplane and ground spraying, and the gorse was all over 8 ft. tall.

Area 2: Aeroplane area. This also covered 2.8 acres, but the gorse ranged in size from over 8 ft. at one end to about 4 ft. at the northern end.

Area 3: Ground-spray area. This was 1 acre in area and access lines for spraying, each 6 to 8 ft. wide, were crushed in parallel lines across the block at 30-ft. intervals.

Within each of the helicopter and aeroplane areas, two narrow rows (about 3 ft. wide) were cut, to allow access for placing of cards within

the gorse bushes. These rows were at right angles to the line of flight of the aircraft. No cards were placed within Area 3 (ground spray) and no detailed measurements of spray distribution were made within that area.

Measurement Technique

Narrow tracks (Rows 1 and 2) were cut within Areas 1 and 2 and groups of 5 cards were placed at 6-ft. intervals along these tracks. These cards were each approximately 4 in. × 3 in., and were sensitized by rubbing on dry magenta dye. This dye was dissolved by the spray drops and "fixed" in the absorbent cardboard used. The positions of the cards were as follows:

In the "top" of the gorse, as high as could be reached from the ground (sometimes this was about 2 ft. below the top layer of gorse) three cards were placed, one horizontal and two vertical. One of the vertical cards was parallel to the line of flight of the aircraft and one was at right angles to the line of flight. A fourth card was placed horizontally about 3 to 4 ft. from the ground (the "middle" card), and a fifth card, also horizontal, as near to the ground as practicable (the "bottom" card). The cards were placed well within the gorse bushes at the side of the track, at various distances according to ease of access. These cards were identified as follows:

1. Top:	horizontal:	upwards side	F T
		downwards	F B
2. Top:	parallel to line of flight:	side away from cross-wind	P T
		side facing cross-wind	P B
3. Top:	across line of flight:	side away from oncoming aircraft	V T
		side facing oncoming aircraft	V B
4. Middle:	horizontal:	upwards side	M T
		downwards side	M B
5. Bottom:	horizontal	upwards side	B T
		downwards side	B B

In addition to these cards, two continuous strips of sensitized paper 120 ft. long were laid out on boards about 6 ft. high in the cleared areas adjacent to the aeroplane and helicopter blocks respectively. These were taken down after measuring a single run of each machine.

During the trial, a light wind of about 6 to 10 m.p.h. was blowing fairly constantly. The mean direction of this wind was approximately at right-angles to the line of flight.

Description of Machines and Their Operation

These were as follows:

(a) Hiller 12B helicopter fitted with spray boom 30 ft. wide carrying alternately fan and cone nozzles (in all 66 jets) at 12-in intervals.

(b) Tiger moth plane with regular spray equipment, spray boom 28 ft. 3 in. wide fitted with simple aperture nozzles at 10-in. intervals, none being under the fuselage.

(c) Trailer-unit delivering 150 gallons spray mix per hour through a hand-gun with $\frac{1}{8}$ in. tap (Model 70, Ivon Watkins Ltd.).

One gallon of Butoxone (butyl ester of 2,4,5-T of 3.6 lb. acid equivalent per gallon) was applied to each acre by all 3 units. The helicopter and the aeroplane each applied this quantity in 28.2 gallons of spray mix per acre. The ground unit applied 900 gallons of spray mix per acre. Water was the diluent used in all cases.

Both the helicopter and the aeroplane took about 20 minutes to cover 2.8 acres. The ground unit took about 7 hours to spray one acre.

The first flight of the helicopter (Run 1) was made near to the outside edge of the gorse and probably was not wholly within the trial area. A second flight (Run 2) was therefore made about 2 chains from the edge.

The aeroplane made a single run in the centre of its block (Area 2). After each flight of the helicopter and aeroplane, cards affected by spray were removed. These represented, therefore, two single runs of the helicopter and one single run of the aeroplane. For each run, two series of samples were available (Row 1 and Row 2) (Fig. 2).

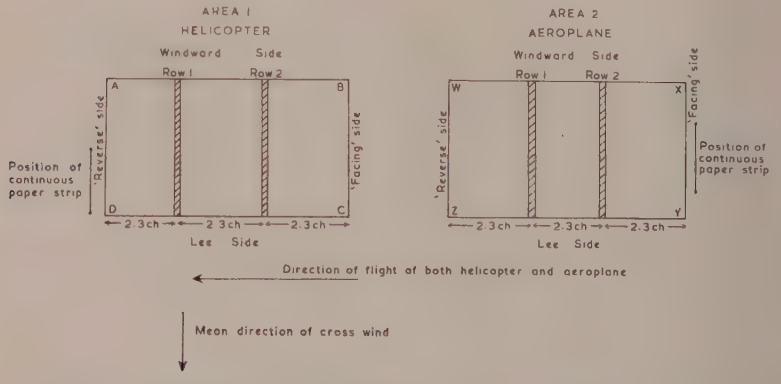

Fig. 2.—Details of Area 1 (helicopter) and Area 2 (aeroplane). AD and WZ "Reverse" sides; BC and XY "Facing" sides. AB and WX "Windward" sides; DC and ZY "Lee" sides.

After completion of the single runs the helicopter and the aeroplane covered the area as completely as possible and in a manner the pilots concerned considered would be done in a commercial operation. A series of parallel flights was made across the target area, all spraying being done when the aircraft was moving in the direction indicated in Fig. 2. However, the aeroplane also made two flights at right angles to the main flight line at each end of the block at the conclusion of the commercial operation. Cards not marked by either of the two single runs of the helicopter or the one run of the aeroplane were used to measure the efficiency of these commercial operations, and were not removed until spraying was completed. The helicopter made an average

of 4 runs over each unit area in this operation, and the aeroplane considerably more, probably 6 to 8. The helicopter flew at about 25 to 30 m.p.h. and about 20 to 25 ft. above ground surface, or 12 to 18 ft. above the top of the gorse. The aeroplane flew about 60 to 70 m.p.h. and from 30 to 40 ft. above ground surface.

The weather was fine and hot for both operations, although the relative humidity was high.

Figures 1 and 2 illustrate the details described above.

Method of Assessing Spray Cover and Droplet Size

The cards marked by spray were each independently assessed by 3 or 4 observers for the following points:

(1) Coverage: scale from 0 (less than 2 or 3 fine drops) to 10 (practically complete cover).

(2) Droplet size: scale from 1 (very fine drops, barely visible) to 5 (coarse drops about $\frac{3}{8}$ in. diameter).

Cards for "1st Run, Row 1 of helicopter" were assessed jointly by all observers to arrive at acceptable uniform standards. Standard cards were then used to assist in judging the other "runs". If a range of droplet sizes was present, this was shown as, for example 2/4. The mean assessments of 3 or 4 observers were subsequently calculated to give figures for the data reported in this paper. A high order of agreement between observers was noted.

Figure 3 shows the standard cards used in these assessments.

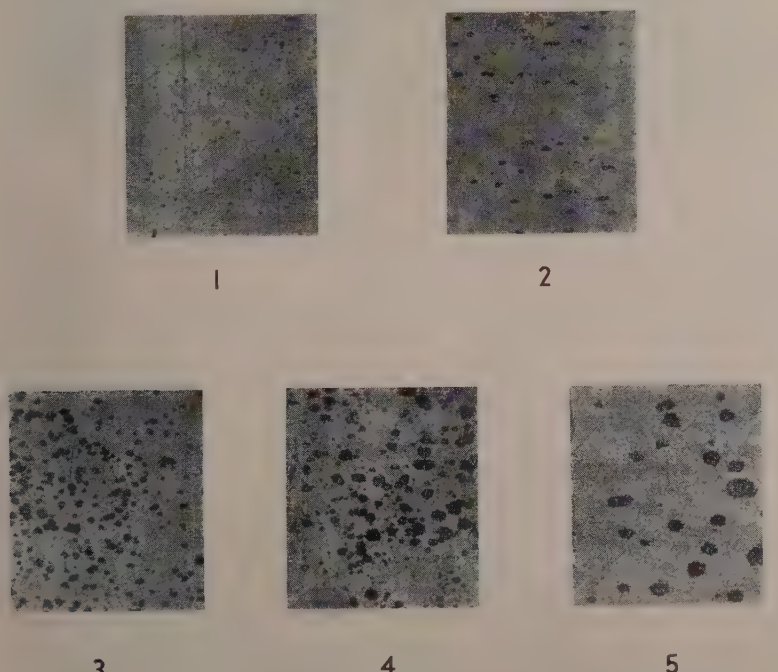

Fig. 3a.—Coverage assessment cards.

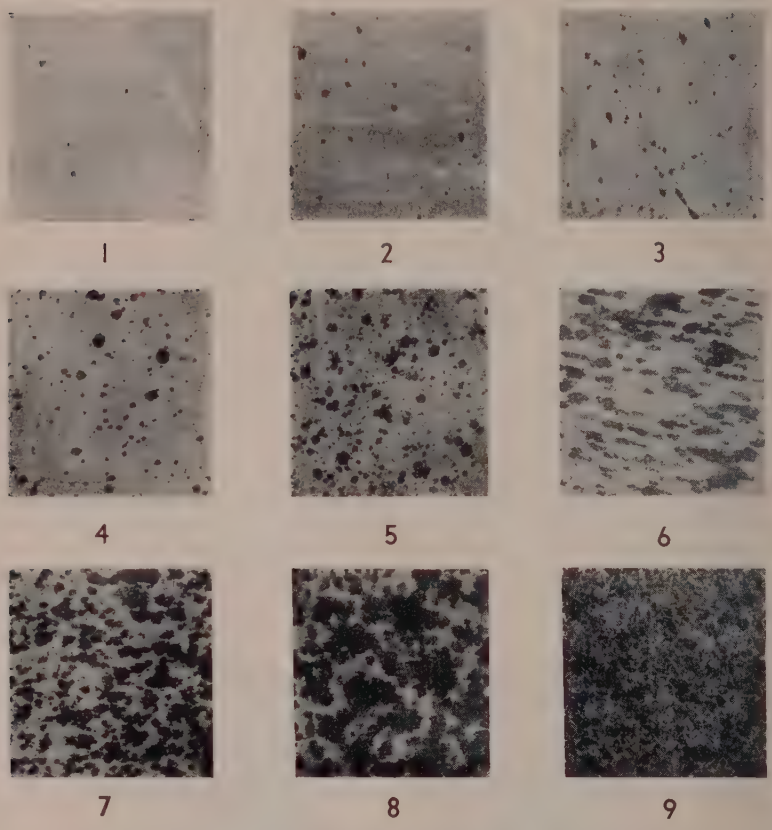

Fig. 3b.—Fineness assessment cards.

Results

Single Runs

Coverage Data

Table 1 gives mean coverage data, assessed as indicated above, for single runs of helicopter and aeroplane. This table shows horizontal cards only. The procedure followed was to take all 5 cards at each sampling position when at least one of these showed evidence of spray. In almost all cases this included the "top — horizontal" card and the mean figures for all other cards include a number of blank cards.

Examination of graphs of spread show clearly that Run 2 of the helicopter was faulty—it appears likely that the spray nozzles on one side were not receiving the normal quantity of spray, possibly due to a temporary blockage. For this reason, Run 1 only has been used in the following summary of Table 1.

This summary indicates that the swath width from the aeroplane is slightly less than twice that of the helicopter and the mean coverage

TABLE 1. MEAN SPRAY COVERAGE ASSESSED FROM HORIZONTAL CARDS (AVERAGES OF POINTS)

Machine	Run	Row	Swath Width	Coverage of Cards		
				Top	Middle	Bottom
Helicopter	1	1	*60 + ft	4.7	3.3	2.0
Helicopter	1	2	*60 + ft	5.2	2.8	2.2
Helicopter	2	1	78 ft.	3.0	1.3	1.9
Helicopter	2	2	66 ft.	2.0	1.0	1.6
Aeroplane	1	1	114 ft.	2.8	1.3	0.8
Aeroplane	1	2	120 ft.	3.0	1.7	1.2

* Assessed: this run was not wholly within the target area. The mean spray coverage figures for Run 1 may be slightly over-estimated as the edge of the swath outside the target area, and not recorded on cards, would probably have a lower spray density than the more central portions.

Machine	Swath Width (approx.)	Mean Coverage (Points)		
		Top	Middle	Bottom
Helicopter	1 chain	5	3	2
Aeroplane	110 – 120 ft.	3	1½	1

pointing is about half that assessed for the helicopter. In none of the cards examined was there more than a trace of spray on the downwards facing side of the horizontal cards.

Continuous Paper Strips. The data assessed from cards are supported by a detailed examination of the continuous paper strip, which may be summarized as follows:

Helicopter. Swath width 50 ft. measured, but probably at least 60 ft. (swath was not wholly within the paper strip). The mean coverage over the 50 ft. on the strip was about 5½, maintained regularly across the swath. As part of the leeward side of this distribution was not recorded, this figure is probably slightly over-estimated.

Aeroplane. Swath width 90 ft. but, of this, 40 ft. had a coverage of 1 or less, and only 17 ft. of 5. Coverage increased from 0 to 5 in first 15 ft. and decreased from 5 to 1 in 10 ft.

Evenness of Spread across Swath. This can be seen most clearly from Fig. 4 which is based on a study of the continuous paper strips. This graph is closely paralleled by the "top" cards to which the paper strips most closely correspond.

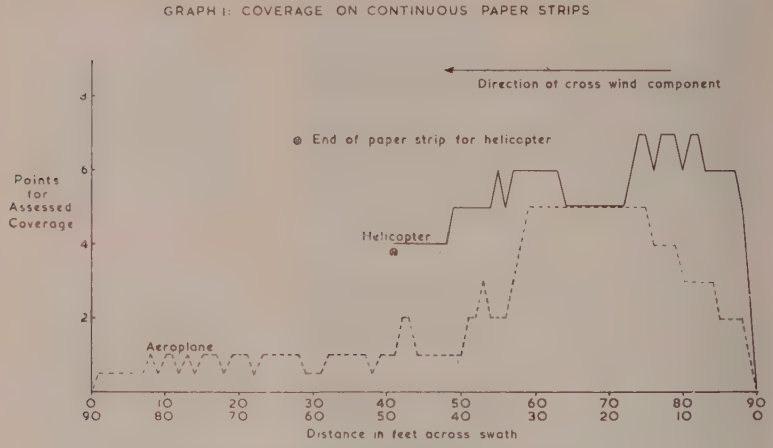
GRAPH 1: COVERAGE ON CONTINUOUS PAPER STRIPS
Direction of cross wind component
End of paper strip for helicopter
Points for Assessed Coverage
Helicopter
Aeroplane
0 10 20 30 40 50 60 70 80 90
90 80 70 60 50 40 30 20 10 0
Distance in feet across swath

Fig. 4.—Coverage on continuous paper strips.

It is clearly demonstrated from Fig. 4 that the helicopter gives a more even density of spray across the swath. On the windward side the point of maximum density is reached much more abruptly with the helicopter. The card measurements also show that the spray pattern from the helicopter is much less affected by wind-drift (see Fig. 5).

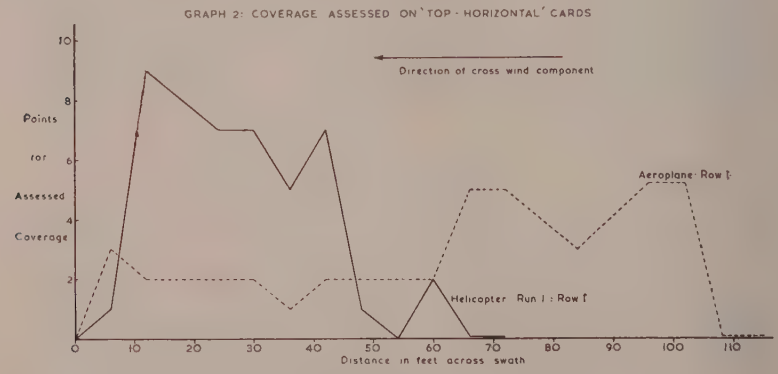
GRAPH 2: COVERAGE ASSESSED ON 'TOP-HORIZONTAL' CARDS
Direction of cross wind component
Points for Assessed Coverage
Aeroplane: Row 1
Helicopter Run 1: Row 1
0 10 20 30 40 50 60 70 80 90 100 110
Distance in feet across swath

Fig. 5.—Coverage on "Top-horizontal" cards.

Penetration of Spray into Gorse. Table 1 shows that the coverage assessed falls off rapidly within the gorse. The middle card records about one-half the points awarded to the top card, and the bottom card slightly less than the middle. There is no marked difference between the spray cover from the helicopter and from the aeroplane in this respect. This should not be taken to mean that half the spray reached the middle card. It is unlikely that the differences from one pointing to the next of the standards used to assess coverage represented equal amounts in area of card affected by spray over the whole range from 0 to 10.

Coverage on Cards Hanging Vertically. Table 2 summarizes mean assessments of coverage on vertical cards (omitting Run 2 of helicopter).

TABLE 2. MEAN SPRAY COVERAGE ASSESSED FROM VERTICAL CARDS

Machine	Row	Coverage of Cards			
		Cards Parallel to Line of Flight		Cards across Line of Flight	
		Lee Side	Windward Side	*Facing Side	Reverse Side
Helicopter	1	1.4	2.9	1.4	2.8
Helicopter	2	3.0	2.0	3.0	1.1
Aeroplane	1	0.5	1.6	0.2	2.1
Aeroplane	2	0.3	2.0	0.6	2.0

*Side facing oncoming aircraft.

Table 2 shows that, although results with the helicopter on vertical cards are much more variable between rows, the average cover on both sides of vertical cards is much better with the helicopter than with the aeroplane. With the aeroplane, the coverage on the lee side of the cards, and on the side facing the oncoming aircraft, is negligible.

The variable nature of the helicopter data in this respect is illustrated more clearly by a study of graphs of coverage across the swath. Fig. 6 illustrates this. This graph shows helicopter and aeroplane spray distributions on vertical cards.

Droplet Size Distribution

Table 3 gives, for each type of card, the percentage frequency of occurrence of each droplet size assessed as indicated earlier. Where a range of droplet sizes occurred on a card, each size within that range was recorded individually.

The following conclusions can be drawn from a study of Table 3 and Figs. 7, 8, 9.

1. The outstanding feature is the greater proportion of fine drops in the spray from the aeroplane (Fig. 7). This occurs in all comparisons, except in the V T cards (vertical cards, across the line of flight, "reverse" side, away from oncoming aircraft). In this case the difference is small, with some tendency for a greater proportion of larger drops in the aeroplane spray.
2. All horizontal cards show a reasonable mixture of droplet sizes.
3. There is a slight but fairly definite tendency for the cards within the gorse bush (middle and bottom) to show a greater proportion of fine drops and a lower proportion of coarse drops, than the "top" cards (Fig. 8). It seems likely that finely-divided spray particles penetrated better than the coarse, although the possibility also exists that some of the coarse drops were broken up in their passage

GRAPH 3: ASSESSED COVERAGE ON VERTICAL CARDS

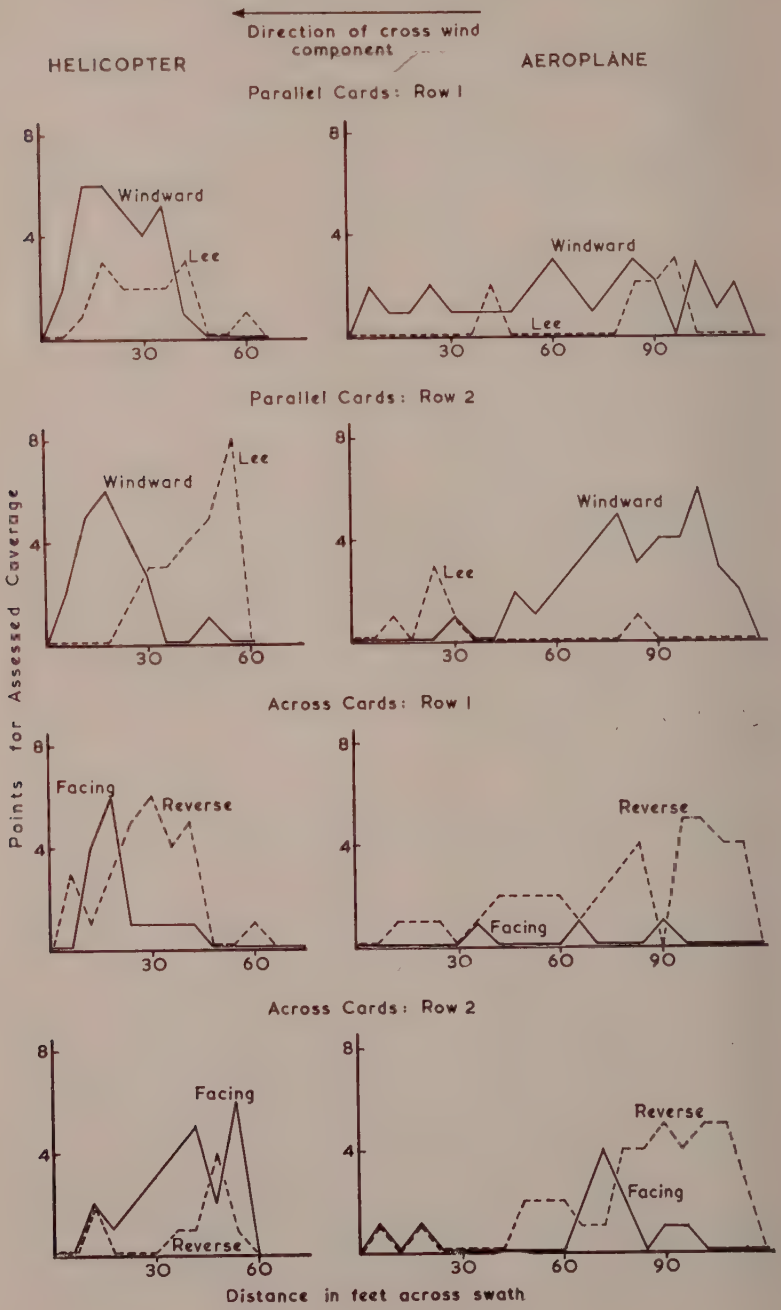

Fig. 6.—Coverage on vertical cards.

TABLE 3. DISTRIBUTION OF DROPLET SIZES
(Means Rows 1 and 2)

Type of Card	Assessed Droplet Size	Numbers of Cards		Percentage Occurrence	
		Helicopter	Aeroplane	Helicopter	Aeroplane
Top—Horizontal (F T)	1	1	15	3	16
	2	9	27	27	30
	3	8	19	24	21
	4	6	17	18	18
	5	10	13	30	15
Middle—Horizontal (M T)	1	3	13	11	22
	2	5	23	19	40
	3	9	13	34	22
	4	5	5	19	9
	5	5	4	19	7
Bottom—Horizontal (B T)	1	3	5	10	12
	2	10	17	35	41
	3	8	11	27	25
	4	6	6	21	14
	5	2	3	6	7
Parallel—Lee (P T)	1	5	3	33	30
	2	4	5	27	50
	3	4	2	27	20
	4	2	—	13	—
	5	—	—	—	—
Parallel—Windward (P B)	1	2	13	11	26
	2	4	17	22	33
	3	5	16	28	31
	4	4	4	22	8
	5	3	1	16	2
Across—"Reverse" (V T)	1	6	17	37	30
	2	5	17	32	30
	3	3	14	19	25
	4	2	7	12	12
	5	—	2	—	3
Across—"Facing" (V B)	1	1	2	5	18
	2	8	8	42	73
	3	7	1	37	10
	4	2	—	11	—
	5	1	—	5	—

through the gorse. It is felt that this effect would be small, as there would be a strong tendency for most drops to remain on the gorse stem or leaf first hit.

4. In the vertical cards, parallel to line of flight, the lee side shows a much higher proportion of fine drops than the windward-facing side.

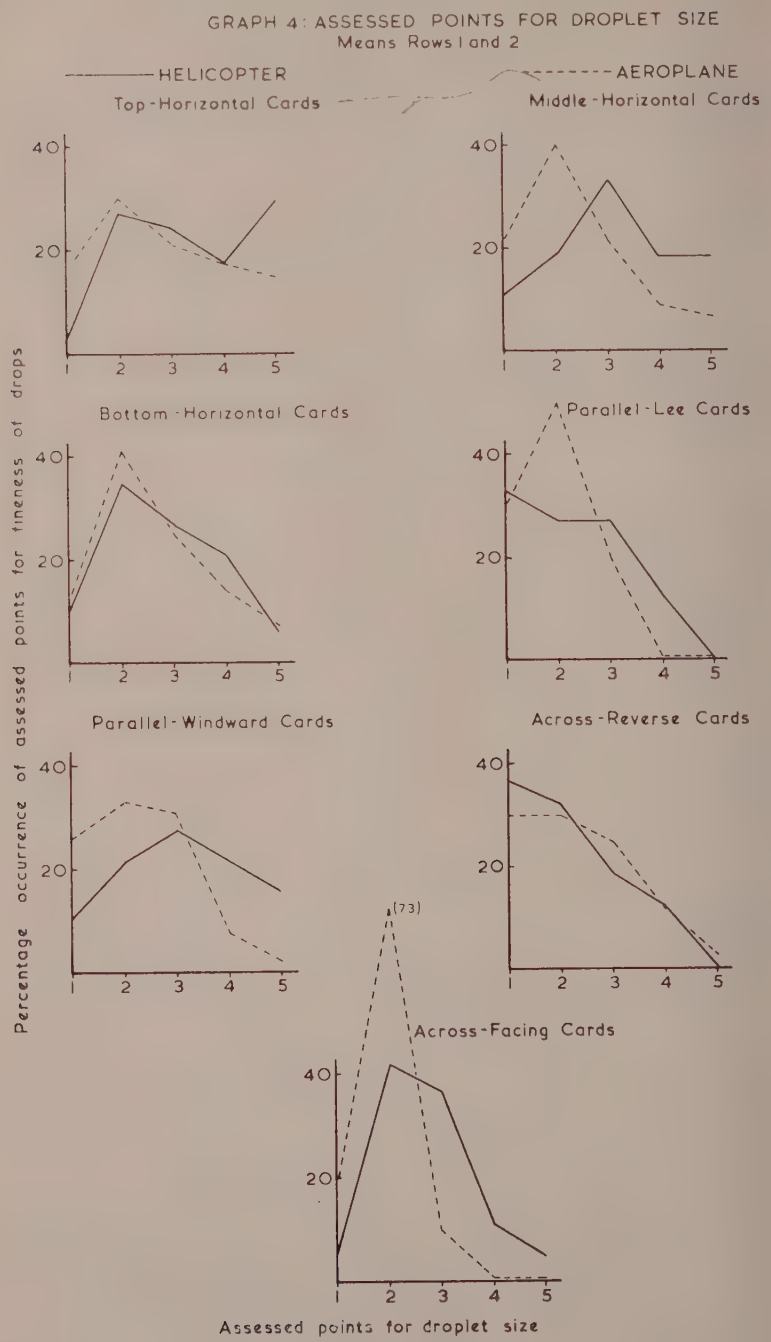

Fig. 7.—Distribution of droplet size.

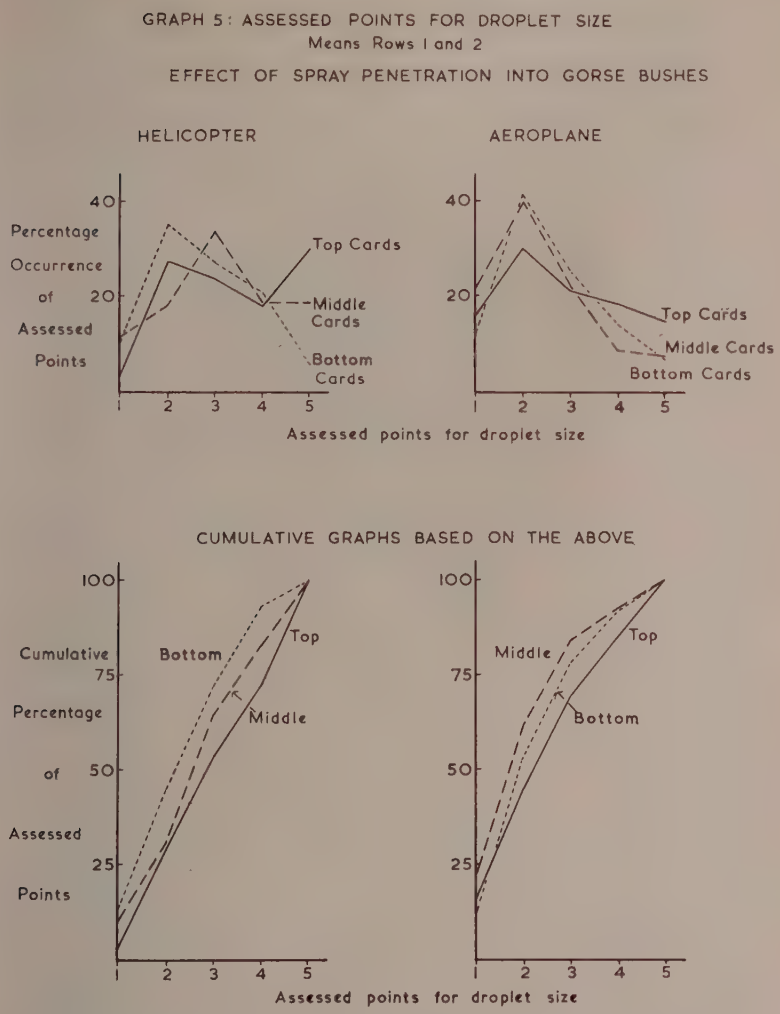

Fig. 8.—Distribution of droplet size: effect of spray penetration into gorse bushes.

5. The fine particles are carried greater distances by wind-drift. This is particularly noticeable in the spray-pattern from the aeroplane, where coarse drops are found directly under the 'plane and fine drops to one side where they have been carried by wind. This separation is much less marked in the case of the helicopter. In the paper strip, for instance, the helicopter pattern showed a good mixture of droplet sizes over the whole range of spread; with the aeroplane, however, the pattern varied from coarse at one side to fine at the other, in the wind-drift area. When the coverage was over 2, the droplets ranged in size from 2 to 5, but in the extensive

wind-drift area, with coverage less than 2, the droplet sizes were mainly in the 2/3 range (Fig. 9).

6. The "top horizontal" cards have a greater proportion of coarse drops than the vertical cards. This is especially the case with the aeroplane distribution where even in the case of vertical cards that had high coverage figures, the droplet sizes were small.

GRAPH 6: ASSESSED POINTS FOR DROPLET SIZE ON CONTINUOUS PAPER STRIPS

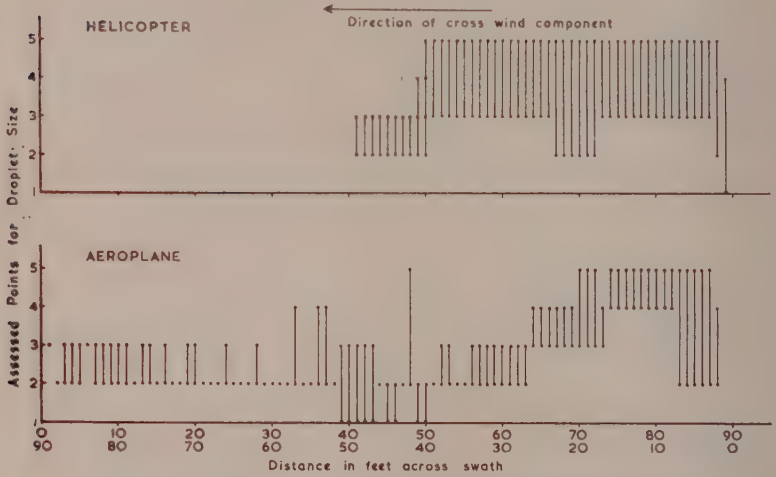

Fig. 9.—Distribution of droplet size on continuous paper strips.

Commercial Operations

Coverage Data

Table 4 gives the mean spray coverage, assessed in a manner similar to that illustrated in Table 1.

TABLE 4. MEAN SPRAY COVERAGE ASSESSED FROM HORIZONTAL CARDS

Machine	Row	Coverage of Cards in Points		
		Top	Middle	Bottom
Helicopter	1	4.5	3.2	2.8
	2	4.5	3.2	2.3
	Mean	4.5 (5)	3.2 (3)	2.6 (2)
Aeroplane	1	5.5	3.4	2.8
	2	7.2	4.3	4.1
	Mean	6.3 (3)	3.8 (1½)	3.4 (1)

(Single run means shown in brackets for comparison)

The underneath sides of the cards were not affected, except in the case of Row 2, top cards, where the helicopter had a mean coverage of 0.4 and the aeroplane of 1.4.

Table 4 shows the aeroplane to have given appreciably better coverage than the helicopter. However, Row 2 of the aeroplane pattern is unduly high and may have received some spray from one of the two final runs which were made at right angles to the general line of flight; in other words, a spray run along the line of cards. If Row 1 is used to compare with helicopter figures, the differences are much smaller, but are still in favour of the aeroplane, especially in the case of "top" cards.

Coverage on Cards Hanging Vertically. Table 5 gives assessments of coverage on cards hanging vertically, omitting Row 2 of aeroplane (see before).

TABLE 5. MEAN SPRAY COVERAGE ASSESSED FROM VERTICAL CARDS

Machine	Row	Coverage of Cards			
		Parallel to Line of Flight		Across Line of Flight	
		Lee Side	Windward Side	*Facing Side	Reverse Side
Helicopter	1	1.3	2.2	0.8	2.5
Helicopter	2	1.2	3.0	1.7	2.9
Aeroplane	1	2.1	3.1	0.9	4.5

*Side facing oncoming aircraft.

As all runs of both helicopter and aeroplane (except two final runs of the aeroplane) were made in the same direction as the "single runs", Table 5 is directly comparable with Table 2 which is based on studies of single runs. With the aeroplane, although the lee and facing sides again show a less dense cover than the windward and reverse sides respectively, nevertheless these have an appreciable spray coverage. Particularly is this the case on the "parallel — lee side" cards which now show greater density than with the helicopter. The overall figures for the helicopter are actually lower than was the case with the single run. This also applies to the "top — horizontal" cards. This suggests the possibility of uneven coverage due to the inability of the helicopter to maintain an evenly-spaced series of parallel runs. This is supported by visual evidence of browning of the gorse some weeks later, considerable areas appearing to have been missed. For the commercial operations cards were not evenly distributed over the area, and it is probable that an unduly high proportion of cards were in these missed areas. In contrast, the browning of gorse over the aeroplane area was remarkably uniform. The intensity of browning on the helicopter area was greatest in that of the strip "Run 1". As the cards were removed from this strip after the single run was made, the remaining area, which received a lower density of spray, was the part measured in the commercial operation for the helicopter.

Droplet Size Distribution

Table 6 has been prepared on lines similar to those of Table 3. The aeroplane data are based on Row 1 only, because of the unsatisfactory nature of Row 2 (see above).

TABLE 6. DISTRIBUTION OF DROPLET SIZES

Type of Card	Assessed Droplet Size	Numbers of Cards		Percentage Occurrence	
		Helicopter	Aeroplane	Helicopter	Aeroplane
Top-Horizontal (F T)	1	13	9	10	12
	2	37	22	29	29
	3	35	21	27	28
	4	25	15	20	20
	5	19	8	14	11
Middle—Horizontal (M T)	1	24	14	23	25
	2	39	21	36	37
	3	31	15	28	26
	4	10	6	9	11
	5	5	1	5	1
Bottom—Horizontal (B T)	1	18	9	22	18
	2	33	21	39	40
	3	24	17	28	34
	4	7	3	9	6
	5	1	1	1	2
Parallel—Lee (P T)	1	14	12	40	28
	2	17	16	48	38
	3	3	12	9	28
	4	1	2	3	5
	5	-	-	-	-
Parallel-Windward (P B)	1	13	3	18	7
	2	25	14	34	34
	3	24	16	34	39
	4	6	5	9	12
	5	3	3	4	7
Across—Reverse (V T)	1	18	9	26	16
	2	32	18	47	32
	3	13	19	20	34
	4	3	7	4	13
	5	2	1	3	5
Across—Facing (V B)	1	6	2	19	13
	2	14	11	44	73
	3	8	2	25	13
	4	3	-	9	-
	5	1	-	3	-

The picture is in many ways similar to that of the "single runs". With the horizontal cards the droplet-size distributions from helicopter and aeroplane are very much alike. All vertical cards except V B cards

(across line of flight, facing oncoming aircraft) indicate a greater proportion of fine droplets with the helicopter. However there was only a small number of aeroplane V B cards that showed any spray drops at all.

2. The middle and bottom cards with both helicopter and aeroplane have a greater proportion of fine droplets than the top cards. This confirms the effect noticed in the "single runs".

3. The "vertical, parallel" cards again show relatively more fine spray particles on the lee than on the windward side.

4. The "top horizontal" cards show a much greater proportion of coarse droplets than do the vertical cards with both machines, confirming the "single run" data.

DISCUSSION

Measurements of distribution were made by means of sensitized cards placed in various ways within the gorse, and by continuous sensitized paper strips erected clear of the gorse and about 6 feet above ground level. For each machine the distribution was measured across the spray swath left by a single run. Measurements were also made following commercial spraying operations which involved a number of runs over each unit area.

The swath width from a single run of the helicopter was about 60 ft. and that from the aeroplane 110 to 120 ft. The mean spray density on upwards-facing horizontal cards in the case of the aeroplane was assessed at about half the value of that of the helicopter. The distribution across the swath was much more even with the helicopter, the spray from the aeroplane being greatly affected by wind drift. The amount of spray penetrating into the gorse bushes fell off rapidly with both machines, and to a similar extent. Cards hanging vertically near the top of gorse bushes received much less spray than horizontally placed cards. A single run from the helicopter gave much more even coverage of these cards than a single run from the aeroplane. With the aeroplane very little spray was deposited on the lee side of such cards or on the side facing the oncoming aircraft.

The data given in respect of the commercial applications have been affected by the inability of the helicopter pilot to space a series of parallel runs evenly across the target area. The aeroplane, on the other hand, was piloted with exceptional skill, and, on the visual evidence of the browning of the gorse from weedkiller applied, made an even coverage of the whole area with spray. This difference in evenness of application is reflected in the data from the sensitized cards, which indicate a more even and more dense distribution of spray with the aeroplane. The overlapping of runs evened out most differences of spray patterns due to wind-drift of spray. Further, the spray coverage on vertically hanging cards in the case of the aeroplane was much better with the commercial operation than in the single runs. It is clear that much of the inferior spray distribution associated with spraying from fixed wing aeroplanes can be overcome by a skilled pilot flying to a pattern of overlapping runs.

In droplet size distribution, the helicopter gives a more even mixture of sizes across the swath. With the aeroplane, the effect of spray drift

from wind is much more marked, coarse drops falling under the 'plane and fine drops being carried down wind. Cards placed within and near the base of the gorse show a greater proportion of fine drops than cards near the top of the gorse. Vertically placed cards show relatively more fine spray than horizontally placed cards, while the side protected from the wind has more fine droplets than the windward side.

Conclusions

From a study of "single run" data, the helicopter shows about half the swath width and gives assessments of spray coverage about twice that of the aeroplane. The evenness of spray distribution is better with the helicopter, the spray from the aeroplane being much more subject to wind-drift. On the other hand, the aeroplane shows the advantage in the commercial operation, although the evidence suggests that this effect may be due, in part at least, to faulty flying technique in the case of the helicopter.

References

Weick, F. E.; Roth, G. A. 1954: Recommended Nozzle Locations for Optimum Patterns. *Proc. 3rd annu. Texas agric. Aviation Conf., 1954.*

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A NOTE ON CONTROL OF CLOVER MITE (*Braeobia praetiosa* Koch) ON *Dianthus chinensis* L.

By H. Jacks, Plant Diseases Division, Department of Scientific and Industrial Research, Auckland.

(Received for publication, 15 November 1955)

Summary

Twelve acaricides were tested in the glasshouse for control of *Braeobia praetiosa* Koch on *Dianthus chinensis* L.

Effective materials are classified according to their mode of action.

Contact effect: Materials based on butylphenoxy isopropyl chloroethyl sulphite, TEPP, malathion, and parathion.

Residual effect: Material based on chlorbenzide.

Contact and residual effect: Materials based on petroleum oil, demeton, and dimefox.

Introduction

The clover mite is a serious pest of a large number of plants, viz. pome fruit, stone fruit, citrus, grape vines, ornamentals, and forest trees. Tests here reported using this mite as test organism and *Dianthus chinensis* L. as host plant were carried out as part of this Division's plant therapeutant-testing programme.

Materials

Aramite (15% butylphenoxy isopropyl chloroethyl sulphite) wettable powder;

Chlorocide (20% chlorbenzide) wettable powder;

Hanane (50% dimefox) liquid;

Malathion (50%) liquid;

Murphos 20 (20% parathion) liquid;

Murphy Tepp (40% TEPP) liquid;

Murvesco (50% p-chlorophenyl benzene sulphonate) wettable powder;

Ovamite (50% p-chlorophenyl p-chlorobenzene sulphonate wettable powder;

Shell Supona DPS (35% diphenyl sulphone) liquid;

Summer oil (80% petroleum oil, viscosity 75 (Red. 1,100°F.) unsulphonated residues 95%) liquid;

Systox (50% demeton) liquid;

Tetrax (70% schradan) liquid;

Experimental Method

Dianthus growing singly in 6-in. pots was used in these tests. Pots were placed in shallow trays containing water. When plants were four

weeks old, 10 adult mites were placed on the two lowest leaves with the aid of a fine brush. Treatments (in 5 single-plant replicates) were carried out four days after mites were transferred to plants. When systemic insecticides (parathion, schradan, demeton, and dimefox) were applied, the surface of the soil was covered to prevent intake of materials by roots, thereby increasing concentrations beyond that obtained by foliage applications. Each series of five plants was sprayed with 100 ml. of insecticidal suspension, a quantity sufficient to wet them thoroughly. Check plants were sprayed with 100 ml. water. After drying, plants were held in a glasshouse at temperatures of 75 ± 5°F.

Mite counts were made at one and twelve days after spraying. The first count was made before mites could have hatched from eggs laid subsequent to infestation. In the second count, however, mites which had hatched after spraying were included. Initial control and any residual effects (chemical residues affecting eggs or mites and systemic poisons affecting mites) were assessed from counts of active mites, eggs not being counted.

Results are given in Table 1.

TABLE 1. Effect of Acaricides on Control of Clover Mite on *Dianthus*

Treatment	Concentration in 100 Gal. Water	Live Mites per Leaf after Treatment			
		Mean No.		Log (x + 1)	
		1 day	12 days	1 day	12 days
Check—water	—	18.6	58.0	1.23	1.74
Aramite	0.5 lb.	0	9.2	0	1.00
Chlorocide	2.5 lb.	7.4	1.8	0.86	0.40
Hanane	0.5 lb.	0	1.2	0	0.24
Malathion	0.5 lb.	0	20.2	0	1.27
Murphos 20	0.5 lb.	0.4	11.6	0.10	1.06
Murphy Tepp	0.5 lb.	0	23.0	0	1.31
Murvesco	1.0 lb.	12.2	4.0	1.04	0.67
Ovamite	1.0 lb.	9.8	6.0	1.02	0.83
Shell Supona DPS	2.5 lb.	3.6	5.8	0.62	0.83
Summer Oil	1.5 gal.	0	0.4	0	0.12
Systox	0.5 lb.	0	0.2	0	0.06
Tetrax	0.5 lb.	3.8	19.6	0.57	1.28
Difference required for significance at 5%				0.31	0.30
" " " " 1%				0.41	0.40

Conclusion

Results confirmed those obtained in tests carried out with the red spider-mite (*Tetranychus urticae* Koch) as test organism, (Jacks, 1955).

Effective control by contact action was brought about by butylphenoxy isopropyl sulphite at 0.007% (Aramite at 0.05%), TEPP at 0.02% (Murphy Tepp at 0.05%) malathion at 0.25% and parathion at 0.01% (Murphos 20 at 0.05%).

Satisfactory control by residual action was given by chlorbenzide at 0.05% (Chlorocide at 0.25%), p-chlorophenyl benzene sulphonate at 0.05% (Murvesco at 0.1%) and p-chlorophenyl p-chlorobenzene sulphonate at 0.05% (Ovamite at 0.05%). Ovamite was less effective than Chlorocide.

Petroleum oil at 1.2% (summer oil at 1.5%) demeton at 0.025% (Systox at 0.05%) and dimefox at 0.025% (Hanane at 0.05%) were effective by contact and residual action. Diphenyl sulphone at 0.08% (Shell Supona DPS at 0.25%) whilst giving significant reduction of mites was not as effective as the above.

Other materials, although significantly reducing the incidence of mites, were not as effective as the above. Schradan (Tetrax) did not as effectively control this mite as *Tetranychus*.

ACKNOWLEDGEMENT

Thanks are given to Dr. H. R. Thompson of the Applied Mathematics Laboratory, Department of Scientific and Industrial Research, who carried out statistical analysis of results.

REFERENCE

JACKS, H. 1955. Screening Tests with Insecticides for Control of Red Spider-mite (*Tetranychus urticae* Koch) on Beans. *N.Z. J. Sci. Tech. A36(5):* 454-9.

DISEASES IN NEW ZEALAND OAT CROPS

By E. C. WRATT, Canterbury Agricultural College, Lincoln

(Received for publication, 18 November 1955)

Summary

The results from disease surveys of 12 oat crops near Lincoln and 77 oat-seed samples from the South Island are reported, and substantiated by results of experiments.

Two pre-emergence diseases occurred. Perceptibly uneven crop growth resulted from infection of the sub-crown internode by *Rhizoctonia solani* whereas bare or thin patches of seedlings occurred in soil infected with *Fusarium avenaceum*.

Helminthosporium avenae causing leaf blotch of seedlings was found to contaminate all lines of Algerian oat seed examined.

The *Puccinia* rusts were the predominant pathogens of maturing crops. *P. coronata* causing crown rust became agressive when the daily maximum temperatures consistently exceeded 60°F. When infection occurred at the flowering stage, the effect on yield was negligible; inoculation 30 days earlier produced the effect of a rust epidemic.

Pseudomonas coronafaciens causing halo blight was prevalent in crops of Garton's Onward and Russet for a 30-day period in October-November.

Ascochyta avenae was concluded to be the cause of small, red leaf-spots apparent on Algerian oats in mid-summer and to be synonymous with *Septoria graminum*.

No specimens of *Erysiphe graminis* (powdery mildew) were secured during monthly inspections of 12 crops near Lincoln.

Ustilago avenae causing loose smut occurred in 50% of Garton's Onward and Dun sowings but in only 3% of Algerians. Smutted heads did not exceed 7% in any one sowing. Spore load per seed had no definite bearing on likely inflorescence infection. *U. kolleri* causing covered smut occurred only in sowings of Duns, in which the heaviest infection was 4.3% of smutted heads. A clear indication was obtained of the value of seed disinfection as a protection against the smuts, and also against *Fusarium* footrot and *Helminthosporium* leaf blotch of seedlings.

INTRODUCTION

The oat crop continues to be an important one in several farming districts of New Zealand. The effect of disease in oat crops was studied at Canterbury Agricultural College, Lincoln, during the 1952 and '53 seasons. The occurrence, distribution, and prevalence of each disease were determined by survey methods. Monthly surveys of twelve oat crops near Lincoln were conducted to determine the diseases occurring in this locality. Eight fungal diseases and one bacterial disease were identified and grouped according to the stage of crop growth affected by them. Two pre-emergence diseases and one disease of the maturing plant are recorded for the first time. A survey of the diseases occurring in oat seed was conducted by collecting 77 samples from the South Island. These samples, representing the three main varieties Algerian, Garton's Onward, and Dun, were firstly examined for disease spores and then sown and observed for infection in a plot trial at Lincoln. The effect of seed disinfection with mercurial dusts was studied, and the relationship between incidence of disease and maturity was investigated by sowing seed at monthly intervals. The three main varieties were compared for resistance to several diseases.

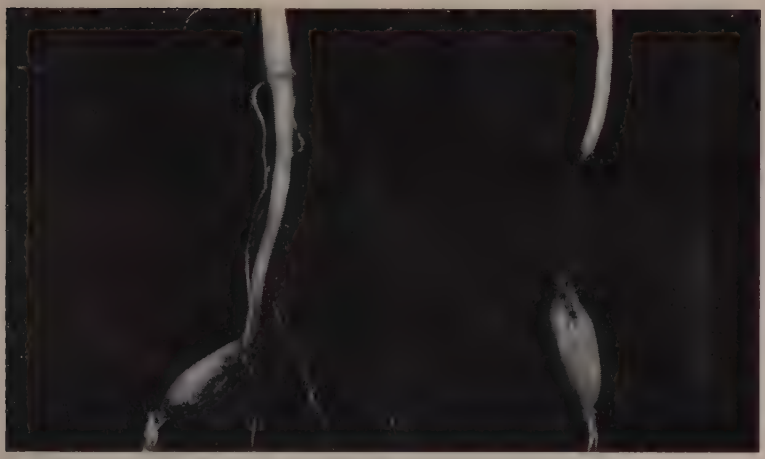

Fig. 1.—*Rhizoctonia solani* Kühn, infecting Garton's Onward oats, showing necrosis of sub-crown internode. Healthy plant on left.

Photo: E. C. Wratt.

PRE-EMERGENCE DISEASES

Rhizoctonia solani Kühn, causing purple patch.

A localized necrosis of the sub-crown internode was detected on many seedlings examined about 30 days after sowing (Fig. 1). *R. solani*, a soil-inhabiting organism not hitherto reported on oats in New Zealand, was isolated from diseased tissue and shown to be distinctly pathogenic on oats. There were up to 5% infected seedlings in 10 out of 12 crops examined, and 7% and 14% respectively in the remaining two crops. Pathogenicity experiments showed that this fungus, though clearly capable of producing necrosis of sub-crown internodes, did not cause decay of germinating seeds.

The purple-patch phase of the disease as described by Hynes (1933) for New South Wales was also observed in a crop of Garton's Onward. This was characterized by yellow, stunted seedlings distributed among patches of apparently healthy plants which in contrast looked like "nitrogen patches". Diseased seedlings, however, had a capacity to recover through the production of secondary roots above the sub-surface constriction, but the subsequent crop was perceptibly uneven in growth.

Fusarium avenaceum (Fr.) Sacc., causing brown footrot.

A field of Algerian oats sown in May at Blenheim showed bare patches extending over about 20% of the area. Seedlings surviving on the periphery of diseased areas were infected with footrot. Fungus cultures were isolated from the roots, and *F. avenaceum* was identified from Bennett's (1928) description. Inoculation tests showed that this *Fusarium* species may also contribute to pre-emergence decay of oats in the same manner as shown by Blair (1938) to be the case with wheat germinating in *Fusarium*-infected soil.

SEEDLING DISEASES

Helminthosporium avenae Eidam, causing leaf blotch.

Recorded in New Zealand by Kirk (1906), this fungus located on or beneath the seed coat gives rise to necrotic blotches with dark margins on leaves, which frequently die as diseased areas extend through the tissues. When disinfected Algerian oat seeds were sown in soil inoculated with cultures of the fungus, it was observed that root systems became severely stunted, but normal growth was resumed when infected seedlings were transplanted to non-inoculated soil. Under field conditions near Lincoln, diseased and healthy seedlings (25 pairs of each) were marked at 100 days after autumn sowing. The following observations were made on their subsequent development.

TABLE 1. EFFECT OF *Helminthosporium* INFECTION ON GROWTH

Soil	Time after Sowing (days)	% Reduction from Control Plants			
		Light Infection		Severe Infection	
		No. of Tillers	Height	No. of Tillers	Height
Light	122	15.2	7.5	43.5	23.4
	146	9.5	2.0	52.4	12.7
	178	5.3	3.0	30.6	15.1
	240	5.6	3.1	27.8	13.7
Heavy	110	17.1	1.0	54.3	27.7
	134	14.8	3.7	31.8	12.8
	166	19.2	4.5	68.1	11.8
	228	8.8	3.0	68.5	15.9

TABLE 2. EFFECT OF *Helminthosporium* INFECTION AT MATURITY

	% Reduction from Uninfected Plants			
	Light Infection		Severe Infection	
	Light Land	Heavy Land	Light Land	Heavy Land
Weight of straw	20.5	24.9	56.8	85.0
Weight of seed	16.6	24.2	50.0	81.8
No. of tillers	5.6	8.8	27.8	68.5
Height	3.1	3.0	13.7	15.9

From these data is seems that *Helminthosporium* leaf blotch can seriously limit growth, especially in dense crops on heavy land.

In view of the evidence of O'Brien and Prentice (1930) and Muskett (1937) that diseased plants arise mostly from infected seed, it seemed desirable to ascertain the extent of contamination of local samples. These were secured from grain merchants throughout the South Island and were sown in spring (August) in a prepared field area. The results are shown in Table 3.

TABLE 3. INCIDENCE OF *Helminthosporium* IN MAIN OAT VARIETIES

% Diseased Seedlings	% Samples Examined		
	Algerian	Dun	Garton's Onward
Nil	—	17	68
Trace	4	17	29
1–10	48	66	3
11–20	32	—	—
21–30	12		
31–40	4		
No. samples	25	18	34

Helminthosporium, therefore, contaminated all Algerian samples, 83% of Duns, and 32% of Garton's Onward. The percentage infection exceeded 10 in 48% of Algerian samples—one line revealing 32% diseased seedlings. Parallel with these observations, counts of diseased plants were made on oats in a demonstration area at Lincoln. At the early tillering stage, leaf blotch was present to the following extent: Algerian 38%; Dun 13%; Garton's Onward 0%; Russet 0%. Before harvest, the disease had spread to the latter two varieties, presumably through spore transfer from primary infection on the Algerian and Dun plots, but it does seem from each of these sets of observations that Garton's Onward possesses a measure of resistance to *H. avenae*. Taking the district figures as a whole, the results from the field plot studies indicate that the incidence of the disease was higher in Southland and Otago than in north Canterbury and Marlborough.

In Scotland, O'Brien and Dennis (1932) showed that *Helminthosporium* infection of oat seedlings can be considerably reduced by disinfecting the seed with a standard organic mercurial disinfectant. In outdoor plots in this investigation the disease was reduced from 13.6% infected plants in untreated sowings to 1.3% where Ceresan (2 oz. per bushel) had been applied. In the same plots, field emergence was also improved, rising from 72% in untreated sowings to 85% under the influence of the mercury dust. These results were statistically significant at the 1% level and 5% level respectively. Agrosan G proved equally effective. The treatments never eradicated the disease entirely. Further investigation with excised embryos demonstrated that some subsurface kernel infection occurs.

Diseases of Maturing Plants

Puccinia coronata Cda., causing crown rust.

Cockayne (1904) stated that in that year 15,000 acres of oats in the North Island were rendered unfit for threshing as the result of an epidemic of crown rust. Twenty-five years later, Neill (1928) reported that *P. coronata* continued to be the predominant oat-rust pathogen.

During the studies now under report, the identity of the organism (and *P. graminis*) was checked against Cunningham's (1931) descriptions. From field plot and survey data it was concluded that the Garton's Onward, Dun, and Winter Grey varieties were highly susceptible to crown rust at Lincoln. It was observed in the 1952 and '53 seasons that the disease changed from a minor to an aggressive infection of these varieties after periods when daily maximum temperatures consistently exceeded 60°F. Furthermore, by this time susceptible varieties had reached the flowering stage. Natural infection of field plots of Garton's Onward at that stage resulted in non-significant differences in crop yield as checked against the yield of plants where rust infection had been prevented by the use of colloidal sulphur spray. Parallel with these observations, potted plants of Garton's Onward and Algerian grown outdoors were inoculated with crown rust at four stages and compared with controls kept free from disease by sulphur spraying. The results are shown in Table 4.

TABLE 4. Effect of Crown-rust Infection on Yield and Seed Weight

Variety	Time of Inoculation	% Reduction from Control Plants	
		Seed Yield	Wt. of 100 Seeds
Garton's Onward (susceptible)	days		
	20	27.5*	22.0**
	55	29.4**	17.2**
	85	13.7	12.0*
	105	+ 2.0	8.9
Algerian (resistant)	20	+14.6	13.5*
	55	2.4	4.7
	85	7.3	4.6
	105	+ 4.9	2.0

** Diff. sig at 1%
* " " " 5%

The differences from control plants of Garton's Onward in respect to grain weight and yield obtained by inoculation after 85 days' growth (the flowering stage) were not significant at the 1% level. This result is substantially the same as that obtained from natural infection in the field plots. On the other hand, highly significant differences were obtained in respect to plants inoculated 30 days earlier, indicating the

time of rust infection during an epidemic year. In contrast, similar treatment of Algerian plants resulted in no such differences. The foliage produced subsequent to inoculation became densely flecked which indicated a resistant rust reaction.

Algerian oats at Lincoln in the 1952–53 season showed distinct resistance to crown rust for one month after infection became aggressive on Garton's Onward (i.e., until New Year). By this time sowings made between May and September, inclusive, had ripened. However, later sowings still vegetative readily acquired the disease indicative that some environmental factor, probably temperature, closely governs resistance and susceptibility to the disease. Peturson (1930) for instance showed that certain varieties were heavily infected by some *P. coronata* races at 77°F. but were resistant at 57°F.

Puccinia graminis Pers., causing stem rust.

Whereas crown rust was observed throughout the 12 crops examined near Lincoln, stem rust, first reported by Kirk in 1894, was less noticeable during 1952–53. All varieties were susceptible to stem rust although autumn-sown Algerian and Winter Grey escaped infection through the fact of their attaining growth maturity before aerial dissemination of uredospores. From field observations made it was evident that stem rust was important chiefly as a factor predisposing late varieties of tall growth habit and heavy inflorescence (as Garton's Onward and Russet) to wind damage in Canterbury. A few uredosori between flag leaf and inflorescence were sufficient to weaken stems and cause them to break over at infection sites with consequent termination of grain development.

Pseudomonas coronafaciens (Elliott) Stapp, causing halo blight.

Recorded by Reid (1938), this disease during 1952–53 was very prevalent on oats in north Canterbury over a 30-day period in October-November. General occurrence of it through the South Island seems likely, as 80% of Garton's Onward seed samples (35) gave rise to infected seedlings when grown in soil beds at Lincoln. Infection levels rarely exceeded 1% of diseased seedlings in Garton's Onward and Russet. No evidence of the disease appeared on any seedlings grown from Algerian or Dun seed.

Ascochyta avenae (Petrak) Sprague & A. G. Johnson, causing leaf spot.

A leaf spot disease was noticed frequently in 1952–53 characterized by small, red spots chiefly apparent on Algerian oats during mid-summer. Pathogenicity was demonstrated, and on the basis of spore measurements Wratt (1954) concluded that the causal fungus was *A. avenae* described by Sprague (1950). This disease could well be synonymous with *Septoria graminum* Des., reported for New Zealand by Cunningham (1927), the original description of which by Desmazieres in 1843, does not according to Weber (1923) include spore measurements.

Erysiphe graminis DC, causing powdery mildew.

In this investigation, 12 crops near Lincoln, including the varieties Algerian, Dun, Garton's Onward, Russet, and Winter Grey, were inspected at monthly intervals, but no specimens of *E. graminis* were secured. It appears that no reported crop survey has yet detected powdery mildew as a disease of oats in New Zealand.

DISEASES OF THE INFLORESCENCE AND SEED

Ustilago avenae (Pers.) Rostr., causing loose smut.

Murphy (1882) stated that specimens of smut (Fig. 2) could be gathered in almost any oat field, and from other reports it seems that smut diseases caused considerable grain loss in the years preceding seed disinfection treatment or the use of selected seed stocks. Loose smut has persisted, however, and Neill (1927) recorded that 14% of crops inspected in one season were severely infected and 37% in the following season, while 10 years later Blair (1937) found that severe infection occured in 20% of the crops he surveyed. He correlated this with the fact that 37% of growers failed to apply the proven method of prevention —seed disinfection.

Fig. 2.—*Ustilago kolleri* Wille., covered smut (left pair), and *U. avenae*, loose smut (right pair), on Garton's Onward and Dun oats.

Photo: Green & Hahn Ltd.

Seventy-seven samples of oat seed of the 1951-52 harvest were secured from South Island merchants. Portions of these samples were examined for *Ustilago* spore contamination by the method described by Blair (1950) and the remaining seeds were sown in August in soil beds, to determine infection levels under field conditions. Infected plants occurred in 50% of all Garton's Onward and Dun sowings but in only 3% of Algerians. Disease incidence did not exceed 7% of smutted heads in any one sample. *Ustilago* spores were detected on nearly all seed samples, spore loads ranging widely from nil to 15,000 per seed. The few samples free from contamination all produced healthy seed heads, but otherwise there was no relationship between percentage of infected heads and spore load of the seed sown. For example, several Algerian samples with spore contamination between 18 and 250 per seed produced no infected plants when grown in field plots; a sample of

Dun oats carrying 1,500 spores per seed produced 0.6% diseased heads; while the same level of field infection arose from the sowing of Dun seed with only 140 spores per seed. Clearly, spore load per seed gives no definite indication of likely inflorescence infection.

Pathogenicity apparently depends upon interaction of environmental factors, and Bayles and Coffman (1929) showed that maximum infection by surface spores required moisture of 30% or less of soil water-holding capacity and a temperature of 62°–65°F. During the investigation under report, soil temperatures were much lower and water content much higher than these levels and under such conditions the amount of disease shown by the field sowings was not in accord with the disease-producing potential of the amount of seed contamination.

Ustilago kolleri Wille., causing covered smut.

The same 77 seed samples were likewise examined for spores of this fungus and every sample was contaminated, in one instance up to 98,000 spores of *U. kolleri* per seed. In field sowings, however, no disease occurred in either Algerian or Garton's Onward, but 28% of Dun sowings produced covered smut in the inflorescence. The heaviest infection was of 4.3% infected heads.

The general occurrence of smut-spore contamination justifies greater endeavours to persuade all concerned to use disinfected seed as a precaution against the probability of severe disease when seed is sown in soil with moisture and temperature conditions favourable to the development of smut.

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A NOTE ON WIND DAMAGE TO TOBACCO

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(Received for publication, 1 November 1955)

During 1, 2, and 3 December 1954, strong winds occurred in the Motueka-Riwaka, Motueka Valley area. The tobacco crop was, in most areas, well established. The plants were about 4 in. high, but more erect than usual owing to drought conditions following the driest spring on record. The total rainfall for September, October, and November was 4.18 in. (13-yr. average 11.49 in.) and over half this (2.37 in.) fell during the first week in September, so that by the end of November soil moisture in non-irrigated areas was approaching wilting point.

Shortly after dawn on 1 December a south-west breeze sprang up. By 9 a.m. the wind from this quarter had freshened to force 4 on the Beaufort scale. At 11 a.m. the velocity had increased to force 6 and soil particles were being lifted to a height of approximately 1 ft. By 1 p.m. the wind had reached force 8 and continued to blow at this strength until 11–12 p.m., when it abated to force 4. At 9 a.m. on 2 December the velocity had risen to force 6–8, still from the south-west, and the wind continued at this strength throughout the day, dropping during the early hours of the following morning. By 9 a.m. on 3 December, the wind was blowing from the south-west at force 4. Shortly after 10 a.m. it shifted rapidly to the north-east, and continued to blow from this quarter at force 4–6 until early in the afternoon.

While blowing above force 5, the wind constantly lifted a dense cloud of soil particles which at force 7–8 was raised to a height of 4–6 ft.

At the Tobacco Research Station, ⅕ acre-inch of water was applied by a sprinkler irrigation plant. This effectively stopped the lifting of soil particles. Rain, which followed a few days after the wind dropped, greatly assisted in the recovery of the crop.

Wind damage to plants was of two types:

Damage due to wind alone. Wind damage occurred throughout the district and was severe in exposed positions. It consisted of torn and ragged leaf margins, and ragged holes where the wind buffetted one leaf against another.

Damage due to the abrasive action of soil particles. This has a serious effect on the final yield and quality of the crop, delaying maturity, so that the tip leaf fails to ripen. In severe cases flying soil particles grind the laminal portion of the leaf from the plant, leaving a blackened stem and mid-veins. In less severe cases the abrasive action of the soil particles results in necrosis of the leaf tissue and the plant presents a withered appearance. Under suitable conditions, re-growth of the plant occurs from axillary buds but very often death of the plant results.

Intensity of Damage According to Soil Texture

The areas on the Tobacco Research Station damaged by abrasive action of soil particles were plotted and graded according to the intensity of the injury. The degree of damage was classified as follows:—

Light: Some lamina removed, the remainder showing numerous necrotic areas. Net-veins still present.

Moderate: Lamina and net-veins completely removed.

Severe: Mid-veins withered, main stem blackened.

The intensity of damage was examined in relation to soil texture. Sandy loams and fine sands did not blow readily but medium, coarse, and gravelly sands blew badly. Blowing occurred on all areas of coarse and gravelly sands, but on medium sands the liability to blow was governed by other soil characteristics. On a large area of medium sand no abrasive damage occurred, but on some areas, which grow a poorer cover crop and produce a lighter tobacco crop, there was considerable damage. Continuous cropping of these areas has possibly depleted the organic matter to such an extent that their structure has been weakened and their moisture-holding capacity lowered, so that their resistance to blowing has been reduced. Soil-moisture determinations showed a range from 8.7% on areas of severe damage to 10.5% on areas where damage was light.

Subsequent Re-growth of Crop

Weather conditions following the wind damage permitted a rapid recovery of the crop but severely damaged plants did not develop as quickly as plants less severely damaged. At harvest, the areas severely damaged by the abrasive action of soil particles could be clearly picked out by their later maturity. A close check was kept to determine whether any unusual incidence of mosaic, predominance of malformed plants, or other diseased condition occurred within the varying classes of abrasive damage. The incidence of mosaic, dwarf plants, and the re-growth of plants is shown in Table 1.

TABLE 1. PERCENTAGE OF PLANTS WITH MOSAIC, DWARF PLANTS, AND PLANTS THAT DIED, ACCORDING TO CLASS OF ABRASIVE DAMAGE

	Light	Moderate	Severe
No. of plants examined	1200	1200	3600
Primary mosaic	0.86	0	0.14
Secondary mosaic	2.73	1.15	0.43
Dwarf plants	9.34	3.45	2.16
Died	0.57	1.0	4.46

Within areas suffering abrasive damage the incidence of mosaic was extremely low, the most heavily damaged areas exhibiting the least infection. This is contrary to expectation. In the past various experiments have demonstrated that even any slight check to the growth of the tobacco plant is followed by the development of mosaic symptoms. Heathers and Pound (1954) have shown that tobacco-mosaic virus multiplies more readily in rapidly growing tissue. Under normal field conditions any mechanical or climatic check to the growth of the plant is usually followed by a period of relatively rapid development and it is

during this period that the symptoms of mosaic become apparent. It was expected that the incidence of mosaic would be progressively greater with increasing severity of damage. However, in this case, the check in growth was not followed by a period of rapid development and it may well be that the relatively late but steady re-growth of the most severely damaged plants did not favour the development of the virus.

Dwarfed plants occurred more frequently in areas suffering light abrasive damage. On these plants no disease symptoms were apparent and they evidently resulted from physical injury to the growing point. They showed normal development except in size. None grew more than eighteen inches high. It appears that where injury is increasingly severe, but not fatal, the plant makes a more complete recovery. With increasing severity of abrasive damage there was an increase in the number of plants which died. This was the expected result.

On areas which suffered wind damage alone, the incidence of mosaic was greater than that in plants subject to abrasive damage. No plants were killed as a result of wind damage alone, nor did any dwarfed plants occur.

No other unusual growth habits were apparent in either the wind or abrasive damaged areas and the pattern of re-growth, apart from the development of dwarfed plants, closely followed that of a previous trial in which plants were decapitated and allowed to re-grow from axillary buds. In this trial maturity was considerably delayed and the resultant final yield appreciably decreased.

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THE USE OF DRIED BUTTERMILK IN A MEAL MIXTURE AS A FEED FOR DAIRY CALVES

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(Received for publication, 14 September 1955)

Summary

A trial is described in which calves were reared on whole milk for the first 3 weeks of life, and, after a gradual change in diet taking two weeks, were fed for a further four weeks on gruel or dry meal prepared from two mixtures of meals, one containing buttermilk powder, maize meal, and pollard, and another containing wheat meal instead of maize meal.

Calves that received their rations in the form of a gruel made faster weight gains than those fed their rations in the form of a dry mixture. No difference was observed between the mixtures containing maize meal and wheat meal, respectively.

Introduction

Although buttermilk reconstituted from buttermilk powder is a satisfactory substitute for fresh whole or separated milk in the feeding of calves, it is desirable in the interests of economy to determine whether part of the buttermilk can be replaced by cereals, which are normally cheaper. It is also desirable to determine whether, in the interests of ease and economy in labour in feeding calves, a mixture of dried buttermilk and cereals can be fed in the dry condition. The experiment described in this paper was carried out to study these questions.

"Gruels" prepared from dried whey and cereals were widely and successfully used in the United Kingdom for feeding to calves that received only limited amounts of whole milk. However, in recent years dry calf starters have replaced gruels on many farms. The necessity of care regarding the temperature of the gruels and the labour and time required for making them and for cleaning the pails has decreased their popularity. Morrison (1950) and Converse (1949) describe various experiments using gruels and dry meals for rearing dairy calves.

Experimental Material and Methods

Experimental design. The design was a 2 x 2 factorial one. Two methods of feeding and two different mixtures of meal and dried buttermilk were employed. There were four groups of calves with 8 calves per group.

The two mixtures used were as follows:—

A. Dried buttermilk	40%	B. Dried buttermilk	40%
Maize meal	30%	Wheat meal	30%
Pollard	30%	Pollard	30%

Feeding and Management. The gruel ration was made up by mixing one part of meal mix with 3 parts of warm water and it was fed at the rate of 7% of body weight. The dry meal was fed at the rate of 2% of body weight. Thus both gruel-fed and dry-meal-fed calves received the same weight of meal. The rate of feeding of both gruel

and dry meal insured a dry-matter intake approximate to that with whole milk. The calves were fed twice daily at the morning and evening milking. For the first three weeks all the calves received whole milk at the rate of 12½% of body weight. From three to five weeks of age the calves were gradually changed over to either gruel or dry-meal feeding and from five to ten weeks they received no whole milk at all. At all times the calves were rotationally grazed on good-quality pasture. As the dry-meal-fed calves took longer to consume their ration, both groups were kept off pasture for about two hours at each feed. All the calves were weighed once a week on a scale accurate to 1 lb.

RESULTS

Fig. 1 shows the average growth curves for the four groups of calves. It shows clearly that the group of calves that weighed heavier at the beginning of the experiment gained in weight at a faster rate than other groups that initially had a lower body weight. Thus, to allow for the regression of gain in weight associated with initial weight, co-variance analysis was carried out on the data.

Two analyses were made, the first using initial body weight as the independent variable, and gain in weight from 3 to 10 weeks as the dependent variable, and a second using 3-weeks weight as the independent variable.

For the first analysis the correlation between initial live weight and gain in weight from 3 to 10 weeks within treatments was 0.531, for the second analysis it was 0.555. Both were highly significant, and in both cases the reduction of the variance due to the regression was also highly significant.

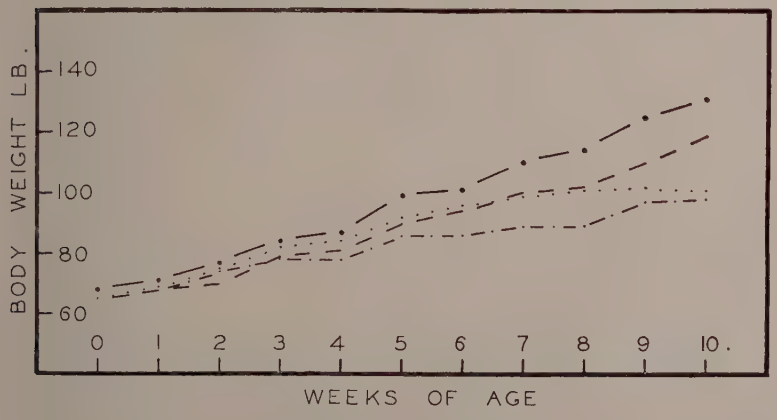

Fig 1.—The average growth curves of each of the four groups of calves, ... A Mix, dry fed; .———— . ———— . B Mix, gruel fed; . —— . —— . B Mix, dry fed; - - - - - A Mix, gruel fed.

Table 1 shows the analysis of covariance using 3-weeks weight as the independent variable and gain in weight from 3 to 10 weeks.

TABLE 1. ANALYSIS OF COVARIANCE

Source	d.f.	S_x2	S_xy	Sy^2	S.S.	d.f.	M.S.	F.
Total	31	6271	4398	11142		30		
B. Treatments	3	195	482	2938				
B. Methods	1	21	231	2554				
B. Mixes	1	3	—5	4				
Mixes x Methods	1	171	256	380				
Within treatments (error)	28	6076	3916	8204	5680	27	210.37	
Methods and error	29	6097	4147	10758	7937	28		
Methods					2257	1	2257	10.74**
Mixes and error	29	6079	3911	8208	5692	28		
Mixes					12	1	12	N.S.
Interaction and error	29	6247	4172	8584	5798	28		
Interaction					118	1	118	N.S.

** Significant at 1% level

TABLE 2. ADJUSTED MEAN WEIGHT GAINS FROM 3 TO 10 WEEKS

	Gruel-fed Group	Dry-meal-fed Group	Means for Mixes
Mix A	41.33	28.39	34.86
Mix B	44.07	23.34	33.71
Means for methods of feeding	41.70	25.86	

Table 2 shows the mean gains per group adjusted for the regression.

The mean difference in weight gains between the groups of calves fed by the two methods was 16.84 lb. in 7 weeks or 2.41 lb. per week. The mean difference in weight gains between the two groups of calves fed the two types of mixes was 1.15 lb. in 7 weeks or 0.16 lb. per week. The difference in weight gains due to the two methods of feeding was highly significant. This was not the case with the two mixes.

During the early part of the trial, while the calves were being changed over from whole milk to both gruel and dry mix feeding, there were several cases of nutritional scours. However, there was no difference

between the groups in the incidence of scours though it was observed that the calves receiving the dry mix tended to recover more quickly. Some difficulty was experienced in the feeding of dry meal to the calves. During the change-over period, some calves had to be carefully coaxed to eat their ration and even at the end of the fortnight one or two calves still did not consume all their meals. The calves took much longer to consume the mixtures in the dry form than those that were fed the mixtures as a gruel.

Discussion

The analysis of the results showed that there was no significant difference between the two types of meal mixtures in terms of growth rates of the calves. There was a significant difference between the growth rates of gruel-fed and dry-meal-fed calves. From Fig. 1 it will be seen that at 8 weeks of age the two gruel-fed groups had reached 114 and 102 lb. live weight, the difference being due not to the two types of meal mixtures but probably to the difference in weight of the two groups at the start of the gruel feeding. The growth rates of these gruel-fed animals compare favourably with those calves fed reconstituted dried buttermilk in a previous trial at the Institute (Flux and Patchell 1956). In both trials, however, the growth rates of the calves have been below the standards of growth for Jersey calves proposed by McMeekan (1954). In the paper by Flux and Patchell (1956) after reviewing the evidence it was concluded that even if young calves made weight gains below McMeekan's optimum standards but were healthy then that should be quite satisfactory. It appeared from this trial that replacing part of the dried buttermilk with cheaper cereals was quite successful. Further work is planned to see whether mixtures containing less than 40% dried buttermilk can be used.

The calves fed the mixtures in a dry form made slower weight gains than those fed gruel. This was due to the difficulty of getting the calves to consume the dry meal. It is possible that part of the trouble was trying to get the calves to consume their dry meal at two two-hourly feeds. Dry meal would be difficult to consume over a short period. It is felt that had the calves been able to have free access to the dry meal all the time, they may have made better gains. Further work will be carried out on this aspect.

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THE SIGNIFICANCE OF FACE COVER IN CORRIEDALE AND ROMNEY-CORRIEDALE CROSS SHEEP

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Summary

Approximately 3,000 ewe-year and 600 hogget-year production records, some lifetime, some single-year, of pure Corriedale and Romney-Corriedale cross sheep on the Ashley Dene farm of Lincoln College have been analysed in relation to face cover. One-third of all ewes were graded covered-faced, a little over one-third were intermediate and a little under one-third were open.

In comparison with open-faced ewes, those with covered faces had 3% more barren ewes, 10–15% fewer lambs born per ewe lambing, 2% higher lamb mortality, and weaned lambs of 3 lb. lower liveweight. Taken together this means a reduction of 23% in lamb production per ewe mated. The corresponding reduction for intermediate-faced ewes was 7%.

Covered-faced ewes clipped 0.2–0.4 lb. more wool per ewe, of slightly higher quality. This is more than can be accounted for in terms of dry ewes, single- and twin-bearing ewes. The ewes were smaller in size and it is estimated that about 3% more covered-faced ewes could be carried per acre. The differences between intermediate and open-faced ewes in these respects are negligible.

It has been shown from an analysis of over 800 ewe records and 560 hogget records that similar differences occur in regard to face cover in the College stud flocks of the Corriedale, Romney, and Southdown breeds.

The importance of culling covered-faced and of selecting for open-faced ewes and rams is emphasized.

Introduction

Early records and photographs of both Corriedale and Romney sheep in New Zealand show that these breeds were once open-faced. Today many of these sheep have a large amount of wool covering on the face and legs. It has commonly been held by breeders that covering of the face and points is an index of high wool weight and quality, and this view has been largely responsible for the increase in face and leg cover of our present-day sheep.

The first investigations on the relationship between face cover and productivity were undertaken in the U.S.A., in fine woolled sheep (Rambouillets) run under range conditions. Of these the most recent and thorough is that reported by Terrill[1] from the U.S. Sheep Experiment Station in Idaho. From an analysis of the lifetime production of nearly 800 Rambouillet ewes he showed that open-faced ewes produced 11 per cent more lambs than covered-faced ewes, this difference being due mainly to a higher percentage of twins born but also to 3–4% fewer barren ewes and a higher viability of the lambs born. The lambs from open-faced ewes were also about 3 lb. heavier in liveweight at weaning. On the other hand the covered-faced ewes produced fleeces weighing approximately 0.2 lb. heavier than those from open-faced ewes. This difference was largely attributable to the greater lamb production borne by the open-faced ewes. In this particular study over 55–60% of the ewes fell into the covered-faced category, 10% in the open-faced,

and the remainder were classified as partially covered. The latter were intermediate in productivity but approximated more closely to the open-faced ewes, so there were greater advantages in going from covered to partially-covered than from partially covered to completely open faces.

In New Zealand, some details of the results of similar studies in the Romney Marsh breed have recently been published. At Massey College, Barton[2] has analysed the production data of a group of 420 Romney ewes during two seasons on easy country. One-third of the ewes classified as open-faced clipped 0.3–0.7 lb. less wool per ewe but produced 14–26% more lambs, weighing 2–3 lb. heavier at weaning than one-third classified as covered-faced. Inkster[3] reporting the effect of face cover on the lifetime production of the Ruakura Hill Country Research Station flock obtained a 0.6-lb. decrease in wool, a 15% increase in lambing percentage, and a 4-lb. increase in weaning weight from open-faced ewes in comparison with covered-faced ones. He found the difference in lambing percentage to be due almost entirely to the low performance of the covered-faced ewes at the two-tooth stage. In the Massey College Romneys, Rae[1] has reported a genetic antagonism between fleece weight and fertility.

The present investigation is an analysis of the effect of face cover in the Corriedale breed, in Romney-Corriedale cross sheep, and to a lesser extent in the College Corriedale, Romney, and Southdown stud flocks.

EXPERIMENTAL MATERIAL AND METHODS

The results of this study are based primarily on the production records of various groups of sheep in the Ashley Dene flock of the College. Two criteria were used in the selection of groups for inclusion in the study; firstly, all sheep within each group must have beeen subjected to identical treatment and, secondly, full production records must be available for all sheep. The study covers the period 1946–55 inclusive and includes the analysis of about 3,000 ewe-year records, some of the latter being lifetime records and others one- or two-year records. In addition to this, a more limited study has been made of the effect of face cover in the Corriedale, Romney Marsh, and Southdown stud flocks of the College maintained on the College home farm. This study covers the period 1952–55 and involves a total of 830 ewe records and 560 hogget records.

It is first necessary to give the background of the breeding of the Ashley Dene flock and to explain the terms Corriedale and Romney-Corriedale used in this text.

Prior to 1942 the Ashley Dene flock consisted entirely of pure grade Corriedales, one half of which were mated to Corriedale rams for breeding replacements, and one half to Southdown rams for fat-lamb production. For the next few years a proportion of the flock was mated to Romney rams from the College stud, with the object of producing a Romney-Corriedale sheep which was considered to be a better fat-lamb producer than the pure Corriedale. When the flock became available for experimental purposes in 1949 there was no accurate record of the breeding of individual ewes, so the flock was divided, according to the appearance of the sheep and the wool count, into groups that were considered to be still pure Corriedale and those that had had a cross of Romney. In 1949 and thereafter, Corriedale rams only (from the

College stud) were used to breed replacements, these being mated to the Corriedale ewes, while Down rams were mated to the ewes showing [illegible] Romney blood. On two occasions Corriedale ewes were bought in and these have been included in the analysis. The records for analysis have therefore been divided into two sections: those appertaining to pure Corriedale sheep and those of the Romney-Corriedale cross. The latter were first-cross ewes. In the pure Corriedale groups there was either no culling of any kind (as in "lifetime" groups) or very little culling, whereas in the Romney-Corriedale groups barren ewes were culled.

The Ashley Dene farm itself consists of flat land, carrying on average 1,600 ewes and 400 ewe hoggets on 878 acres. It is subdivided into paddocks of about 30 acres. Most of the lambs are dropped in the second half of August and early September. The lambing percentage is normally about 110%.

The ewes and hoggets are shorn in November. In February, prior to mating, the ewes are eyewigged and "buttonholed" or "ringcrutched", while the hoggetts are usually eyewigged and crutched at weaning in early January. At the end of June or early July the ewes and hoggets are [illegible] eyewigged and crutched. Only an occasional sheep would be so woolblind before crutching or shearing as to present difficulty in yarding.

Face Grading. Face gradings were invariably made in the winter before crutching. Ewes were graded into three categories—open, intermediate, and covered—with arbitrary standards but based closely on those used by Terrill (*loc. cit.*) for Rambouillets. Fig. 1 as an example shows a set of faces in the six-tooth Corriedale ewes. The first gradings were made in 1950, and thereafter gradings were done annually as required. Some groups were graded several times—as hoggets, two-tooths, and aged sheep; others were graded only once. Face gradings were found to be highly repeatable. With one exception all groups were composed of ewes of the same age, so that age effects on face covering were eliminated.

Liveweight. All ewes were weighed at intervals. For comparative purposes, the weights recorded at the autumn weighing made just before or after mating have been adopted.

Ewe Mortality. Records of the ewes that died were unfortunately not kept. Mean annual mortality is usually of the order of 3%.

Lamb Production. All ewes were ear-tagged and all lambs were tagged at birth. Records of lambs born dead, or dying after tagging and before weaning, were kept. Barren ewes were identified. In the text and tables the following terms have been used—barren ewes or *barrenness* expressed as a percentage, *lambs born* being the number of lambs born dead or alive expressed as a percentage of the ewes lambing and therefore an index of prolificacy, *lambs dying* or lamb mortality being the number of lambs dead at birth or dying before weaning as a percentage of all lambs born, *lambs weaned* being the number of lambs alive at weaning as a percentage of ewes put to the ram, or more strictly as a percentage of ewes present at lambing. A discrepancy of about 1% would result here from the small numbers of ewes that die after mating and before lambing.

Fig. 1.—Six-tooth Corriedale ewes, before crutching, showing typical range of face cover. The top two are covered, centre left and right are on the covered and open side respectively of intermediate, and the bottom two are open-faced.

Weaning Weight. This is the mean weaning weight of the lambs of each category corrected for age and single/twin ratio. The single/twin ratio correction is made to demonstrate any differences between face categories, assuming there are equal numbers of singles and twins. In calculating the liveweight of lamb weaned (relative lamb production) this correction would favour the category with the most twins and so the correction has not been made when calculating the actual weight of lamb weaned.

Relative Lamb Production represents the amount of liveweight of lamb weaned per ewe mated relative to covered-faced ewes standardized at 100.

Fleece Data. Fleece weight is the mean of the weights of all fleeces, including dry ewes, taken at shearing. The fleece weighed consists of that which is picked up and thrown on the table and thus excludes bellies and locks. Count estimations were made on hip samples taken from each fleece. The character scores, based on a scale with scores 1 to 14, were made either on the whole fleece or on hip samples. The mean scores lie within the range medium minus 7, medium plus 8 and good minus 9. A difference of two score units coresponds roughly to a difference of one commercial grade, e.g. between BB and B.

Assemblage of Data. Rather than present a long series of tables for each group, each requiring separate conclusions, the data have been assembled into one table for the pure Corriedale and one for the Romney-Corriedale sheep. First the data for each particular group were analysed. Within each group the sheep had had identical treatment. The means of the different groups could have been averaged, but it was considered of greater merit to obtain a mean by weighting each group according to the number of ewe-years in the group and this practice has been adopted throughout. The variations in production between groups in the same year, and especially in different years, would invalidate the amalgamation of group data on a weighted basis, were it not for the fact that within the Corriedales and within the Romney-Corriedales the percentage of ewes falling into the open, average, and covered categories were very similar in all groups.

Results

Corriedale Ewes

The pure Corriedale ewes from which the following data were obtained consisted of five different groups.

(1) The progeny of 240 Corriedale ewes bought in from north Canterbury and mated to College Corriedale rams in 1946 at the Kirwee Experimental Farm. Data are available from the ewe hoggets in 1947 and from the lifetime production of the 75 ewes that survived to 1952.

(2) The progeny of 240 Corriedale ewes (from Ashley Dene) mated to College rams in 1949. The data cover 120 ewe hoggets in 1950 and the lifetime (four-lambings) production of 83 ewes.

(3) The progeny born in 1951 of College Corriedale rams on Ashley Dene Corriedale ewes. This consists of 140 ewe hogget records in 1952 and the two-tooth and four-tooth production of 1953 and 1954.

(4) A group of 225 four-year ewes by College Corriedale rams out of Ashley Dene Corriedale ewes. Data are available for 1951 only.

(5) A line of 205 Corriedale ewes bought in as two-tooths from north Canterbury in 1953. The data available consists of the two-tooth and four-tooth production records of 1953 and 1954.

(6) 235 ewe hoggets reared in 1955.

The total number of observations was 1,508 ewe-years. It will be seen that most of the information is derived from College Corriedale inheritance, but a little over one-third (half of group 1 and all of group 5) bears no relation to the College stock. The ewe data are given in Table 1.

TABLE 1. LAMB AND WOOL PRODUCTION OF CORRIEDALE EWES IN RELATION TO FACE COVER

Grading	Per cent Grading	Live-weight (lb.)	Lambs Born	Ewes Barren	Lambs Dying	Lambs Weaned	Weaning Weight (lb.)	Relative Lamb Prodn.	Fleece Weight (lb.)	Fleece Count
Open	22	120.1	130.8	4.0	13.8	108.2	62.3	125	8.85	56.7
Intermediate	42	119.3	131.5	7.7	14.9	103.5	62.8	120	8.78	56.5
Covered	36	117.3	121.6	9.5	17.8	88.1	60.9	100	9.01	56.5

Summarizing this table it will be seen that

(i) approximately one-third of the ewes graded "covered faced", one-quarter "open-faced".

(ii) The open-faced ewes were slightly (2–3 lb.) higher in body weight.

(iii) The open-faced ewes produced 10% more lambs per ewe lambing, were 5% less barren, and lost 4% fewer lambs from birth to weaning, weaned lambs 1½ lb. heavier in liveweight, making an overall gain in lamb production of 25% over covered-faced ewes, and 5% over the intermediate-faced ewes.

(iv) In fleece production, the wool count of all three categories was the same, but the covered-faced ewes exceeded the open and averaged-faced ewes in weight by 0.16 to 0.23 lb.

(v) Character scores were obtained in Group 4 only, and these showed no differences between face categories, the actual mean scores being 7.9, 8.0, and 7.9.

In the five constituent groups from which these data were drawn, the only differences that were absolutely consistent were the percentages of lambs born and lambs weaned. In the other characteristics, where differences generally were smaller, there were individual exceptions to the pattern as shown in Table 1, showing that large numbers of observations are necessary in studies of this nature.

The teeth of the ewes from Group 2 were closely examined at 5½ years of age and no differences between face categories were observed.

Corriedale Ewe Hoggets

The data referring to the ewe hoggets (597 hogget-years) are given in Table 2. These figures show that open-faced hoggets are

TABLE 2. Liveweight and Wool Production of Hoggets in Relation to Face Cover

	Per cent Grading	Liveweight 6 Months	Liveweight 18 Months	Fleece Weight	Fleece Count	Fleece Grade
Open	29	69.4	95.3	8.92	56.9	7.84
Intermediate	36	66.6	95.3	8.81	57.3	8.21
Covered	35	64.9	92.5	8.88	57.1	8.56

heavier than covered-faced ones by some 4 or 5 lb. after weaning, the difference decreasing to 3 lb. as two-tooths, the same as in mature ewes (Table 1). Whereas in ewes there is a definite difference in fleece weight between face-cover categories, this appears not to hold in ewe hoggets. The main difference is not in fleece weight or count but in grade. The fleeces from open-faced hoggets have consistently graded slightly inferior to those from covered-faced ones, the mean difference being 0.72 units. As the grading units are double those used in commercial practice, the difference represents approximately one-third of a commercial grade; that is, for example, one-third of the difference between BB and B grades.

Romney-Corriedale Ewe

As already explained, these ewes were first-cross ewes bred by College Romney rams on Ashley Dene Corriedale ewes. The production records of four different groups as listed below have provided material for this analysis.

(1) 242 ewes in the year 1949 comprising two-tooths and four-tooths in the ratio of 2:1. They were mated to various breeds of Down rams. The influence of breed of ram has been neglected in all characteristics except weaning weight where corrections have been made when a disproportionate number of lambs by any one sire occurred in respect to the open, average, and covered-faced categories of ewes. Corrections were also made for slight disproportionate ratios of the three categories in respect of two-tooths versus four-tooths. This group was the only one in the whole study in which two-tooths and older sheep were run in the one mob, thus necessitating an age-correction. The data cover the one year only.

(2) A group of 400 four-tooths mated to a variety of Down sires in 1950. Weaning-weight corrections only were made on account of the sires.

(3) A group of 315 two-tooths mated to Southdown rams in 1950.

(4) A group of 366 six- and eight-tooth ewes mated to Southdown rams in 1951. No corrections for age of ewe have been made in this group.

The data cover of 1,323 ewe-years. As in the Corriedale study, the percentage of ewes in the open, intermediate, and covered categories was very similar in the four groups so it has been considered reasonable to gather the data together in one table—Table 3. In so doing, the data for each group have been weighted according to the number of ewe-years in the group.

TABLE 3. LAMB AND WOOL PRODUCTION OF ROMNEY-CORRIEDALE CROSS EWES IN RELATION TO FACE COVER

	Per cent Grading	Live-weight (lb.)	Lambs Born	Ewes Barren	Lamb Dying	Lambs Weaned	Weaning Weight (lb.)	Relative Lamb Production	Fleece Weight (lb.)	Fleece Count	Fleece Grade
Open	23	123	143.6	6.2	10.1	121.2	70.9	121	9.61	52.5	8.20
Intermediate	50	118	135.1	5.0	12.4	112.3	69.7	112	9.78	53.0	8.25
Covered	27	114	128.0	7.5	12.2	104.1	67.1	100	10.04	53.6	8.40

Before interpreting this table it is neceessary to make one qualification. In the course of grading these crossbred sheep it appeared that the ewes throwing more to the Romney type were more open-faced than those throwing more to the Corriedale type. This is confirmed by the mean count estimations which show the open-faced category to possess a stronger wool consistent with this category having a higher proportion of Romney blood. If count is a linear function of the mean percentage of other Romney characteristics, one can calculate that the open-faced ewes had an apparent 15% more Romney blood than the covered-faced ewes. From some data published by Hart and Stevens[5] and unpublished information at the College, it is considered that pure Romney ewes relative to pure Corriedale ewes would be 10 to 15 lb. heavier in bodyweight, and have 15% more lambs born and weaned, with about 5 lb. higher weaning weight. On the Ashley Dene farm it would be expected that the Romney would give about the same fleece weight and a slightly lower fleece grade than the Corriedale. If this is true, and if again the characteristics are a linear function of the apparent percentage of Romney blood, the calculated 15% higher Romney blood in the open-faced ewes could have an effect of the order of 2 lb. in liveweight, 2% in lambs born and weaned, and 1 lb. in weaning weight. These increments are quite inadequate to explain the observed differences in Table 3 and consequently it is concluded that the differences are genuine effects of face cover.

The conclusions drawn from Table 3 are as follows:

(i) the face gradings were approximately $\frac{1}{4}$ open, $\frac{1}{2}$ intermediate, and $\frac{1}{4}$ covered.

(ii) The open-faced ewes were 9 lb. heavier than the covered-faced ewes.

(iii) The open-faced ewes produced 15% more lambs born and 17% more weaned than the open-faced. The intermediate-faced ewes were half-way between these extremes.

(iv) The differences in barrenness and lamb mortality are small and inconsistent, but together are least in the open-faced ewes by about 2%.

(v) The weaning weight of lambs from open-faced ewes is 4 lb. greater than from closed-faced ewes and 1 lb. greater than from intermediate-faced ewes.

(vi) The wool from the covered-faced ewes exceeds that of open-faced ewes in weight by 0.43 and of intermediate-faced ewes by 0.26 lb., and has a slightly higher grade.

Stud Sheep

Lincoln College owns registered flocks of the following breeds: Corriedale (200), Romney Marsh (150), Southdown (130), Border Leicester (60), and English Leicester (25), the figures in brackets representing the approximate number of ewes mated each year. The material from these flocks is less suitable for analysis than that from Ashley Dene for a number of reasons. The flocks are smaller, the records are not as complete to the extent that no weaning and lamb mortality data are available, and there is a high degree of selection at mating and of culling for barrenness. The purpose of the study in these flocks has been mainly to ascertain whether the conclusions reached in the Ashley Dene flocks could be confirmed in very intensively selected and intensively managed stud flocks.

The ewes were graded for face cover before crutching in the winter of 1955. The previous records of the sheep and the 1955 lambing and shearing records have been analysed. Because the gradings were made after many of the records had been obtained, it is not possible to ascertain barrenness and mortality. The analysis has therefore been restricted to (a) lambs born, being the number of lambs born per hundred ewes lambing, and (b) fleece weight.

The Border and English Leicester flocks were too small to be of much value and in any case, with the exception of a few English Leicesters, all of the ewes were open faced so these two breeds were neglected. The remaining three breeds presented some difficulty in grading. Rightly or wrongly the same standards as adopted for the Ashley Dene sheep were used: the ewes themselves had a greater length of wool than at Ashley Dene; together with the general woolly-faced character of the flocks as a whole all resulted in a very high proportion of ewes grading as covered and a small proportion grading as open. In the event the percentage gradings were approximately as follows:

Corriedale	5% open,	30% intermediate,	65% covered
Romney	20% open,	35% intermediate,	45% covered

TABLE 4. LAMBS BORN AND FLEECE WEIGHT OF CORRIEDALE, ROMNEY, AND SOUTHDOWN SHEEP IN RELATION TO FACE COVER

	Records No.		Lambs Born	Fleece Wt. (lb.)	Hogget Fleece (lb.)
Corriedale	228	Open Intermed.	142	9.47	6.65
		Covered	138	9.77	6.88
Romney	332	Open Intermed.	161	9.98	6.53
		Covered	153	10.17	6.73
Southdown	270	Open Intermed.	154	4.46	—
		Covered	133	4.60	—

Southdown 4% open, 36% intermediate, 60% covered. Because of the small number of open-faced sheep the comparison has been made between open and intermediate on the one hand and covered on the other. The results are summarized in Table 4.

It should be borne in mind that failure to classify the sheep and analyse the data into three sizeable categories must of necessity reduce any inherent differences that occur. In the Ashley Dene sheep the difference between open and covered-faced ewes in regard to lambs born was of the order of +12% and in fleece weight —0.30 lb. In the stud flocks, as shown in Table 4, the percentage of lambs born from the combined open and intermediate-faced categories was in excess of that from the covered-face category by 4% in Corriedales, 8% in Romneys, and 21% in Southdowns. The fleece weight differences were consistently in favour of covered-faced sheep by 0.30 lb. in Corriedales, 0.19 lb. in Romneys and 0.14 lb. in Southdowns. The influence of degree of twinning could not account for more than 0.05 lb. of these differences. In the hoggets there was a difference of 0.23 lb. Corriedales and 0.20 lb. (Romneys) in favour of covered-faced sheep.

The general conclusion is therefore that differences in prolificacy and fleece weight are consistent and of the same order as those occurring in the Ashley Dene flocks and that they occur in all the breeds of sheep, including Southdowns.

DISCUSSION

The results presented show clearly that face cover has a profound effect on the lamb and wool production of ewes. In the analysis of production records, consideration has been given to the pure Corriedales and the Romney-Corriedales separately in the event that face cover effects might operate in a different manner or to a different degree in the two types. The results for the Corriedale in this study and for the pure Romney in those of Barton[2] and Inkster[3] are closely parallel, so one would expect that crossbred sheep from these parent breeds would behave similarly. Within the limits of the numbers of sheep used in all of these studies, this expectation is verified.

Open-faced ewes were better than covered-faced ewes in Corriedales and Romney-Corriedales respectively by 9% and 15% of lambs born per ewe lambing, 5% and 1% of barrenness, 4% and 2% of lamb mortality, 20% and 17% of lambs weaned per ewe mated, 2 and 4 lb. in weaning weight, and 25% and 21% in live weight of lamb weaned per ewe mated. In fleece weight, covered exceeded open-faced ewes by 0.2 and 0.4 lb. respectively for the Corriedale and the Romney-Corriedale. Though some variation exists between the components giving the final lamb production figure the end result of 21–25% more lambs weaned is roughly the same in both series. For this reason it is proposed in subsequent discussion to consider the Corriedales and Romney-Corriedales together, and to regard such variations between the breeds as did exist as being due more to lack of numbers than to real genetic differences. For like reasons the figures given in Tables 1 to 4 might imply an unwarranted exactness, and differences will be considered in terms of "round" figures.

Making first the comparison between *open* and *covered* faced categories it will be seen that *open*-faced ewes had

3% fewer barren ewes

12% more lambs born per ewe lambing
2% lower lamb mortality
3 lb. higher lamb weaning weight
23% higher total lamb production
0.30 lb. lower fleece weight
6 lb. higher body-weight

The sum total of the lamb production factors shows that the open-faced ewes produced 23% more liveweight of lamb at weaning per ewe mated than the covered-faced ewes.

Comparing the *open-* and *intermediate*-faced ewes, the open-faced ones had

1% fewer barren ewes
4% more lambs born per ewe lambing
2% lower lamb mortality
the same lamb weaning weight
7% higher total lamb production
0.05 lb. lower fleece weight
3 lb. higher body weight

In this case the open-faced ewes weaned only 7% more lamb, wool production was scarcely affected at all, and the body weight difference was quite small. Clearly, therefore, the intermediate-faced ewes approximate more closely to open-faced than to the covered-faced ewes.

The data relating to ewe hoggets are more limited, consisting of only 597 hogget-year observations plus 560 stud ewe hogget records. They show, however, that open-faced hoggets are 4 to 5 lb. heavier at 6 months of age and 3 lb. heavier as two-tooths. In both the Corriedale and Romney stud ewe hoggets, the covered-faced hoggets clipped 0.2 lb. more than the others (Table 4). These hoggets were all shorn as lambs, and the fleece measured represents that grown since weaning and shearing. On the other hand, the Ashley Dene hoggets were not shorn as lambs and in this case (Table 2) there are no differences in fleece weight. It is suggested that since all the bodyweight differences are attained by the time the lambs are weaned, the greater thrift and growth rate of open-faced lambs before weaning enhanced their otherwise slower inherent wool growth rate, so that lambs' wool from open-faced lambs might exceed in weight that from covered-faced ones. This could account for the absence of differences in the woolly hogget fleece and a definite difference in the shurl (shorn as a lamb) hogget fleece.

Special mention must be made of wool, for this is a crucial factor in New Zealand sheepfarming. In all studies reported, open-faced ewes have clipped less than covered-faced ewes. Terrill reported a difference of 0.2 lb. in Rambouillets, Barton 0.3–0.7 lb. and Inkster 0.3–0.6 lb. in Romneys, and Coop 0.3 lb. in Corriedales in the present work. From a knowledge of dry ewe, and single- and twin-bearing ewe effects on fleece weight, it can be calculated that the higher lamb production of the open-faced ewes in the above studies would account for not more than 0.10 lb. of the fleece-weight difference. This is quite inadequate to account for the observed differences, and it can only be concluded that covered-faced sheep are more efficient wool producers. The present work suggests that they may also produce wool of a slightly higher

grade. Count estimations made in the Corriedale series and in the Corriedale ewe hoggets show no difference but in the two series where character scores were made, namely in the ewe hoggets (Table 2) and the Romney-Corriedale ewe (Table 3) mean scores of the covered-faced ewes were higher than those of open-faced ewes. In the ewes this may possibly be explicable in terms of the effect of coincident lamb production; even so it must be credited to covered-faced ewes, but it could not account for the slightly superior grade of the hogget wool.

In previous studies, the liveweights of open- and covered-faced ewes have not been reported, presumably because they were not measured. In the present study the ewes were weighed frequently and there is no doubt that a bodyweight difference exists. The difference is of the order of 3–5 lb. in lambs and hoggets, and 5–6 lb. in ewes, the open-faced sheep being the heavier. In terms of production per acre as opposed to production per sheep, this bodyweight difference must be taken into account. The greater number of lambs weaned by the open-faced ewes would undoubtedly require more feed during the spring and early summer. As feed is usually plentiful at these times this may not be any more important than in the winter, since carrying capacity is usually decided by winter feed. The relative carrying capacity of land in terms of open- and covered-faced sheep is unknown and the best that one can do is to estimate maintenance feed requirement on the basis of bodyweight to the power of 0.7. Such an assumption is probably better than no correction at all and would indicate that about 3% more covered-faced ewes could be carried per acre.

The whole picture may therefore be reduced to one in which open-faced ewes produce 23% more lamb and 0.3 lb. or 3% less wool per sheep. On a per-acre basis the comparable figures are probably nearer 18% more lamb and 6% less wool. Even this picture is far from complete. There has been no measure of ewe and hogget mortality. On hill country, open-faced sheep would have a definite advantage in ease of mustering but what the measure of this is in comparison with lamb and wool production is not known. Longevity has been neglected. The only observation in this connection is that reported in this study in one group of Corriedales where no differences were observed in the state of the teeth at $5\frac{1}{2}$ years of age. This one observation is too limited for drawing definite conclusions for there is some evidence from other studies at this College that higher-lamb-producing sheep have a slightly shorter useful life. If this is so, open-faced ewes may be at a slight disadvantage here. On the other hand the higher reproductive rate of open-faced sheep means a greatly increased number of female progeny, thus giving both the stud breeder and the hill-country sheep producer a higher degree of selection. The advantage to the open-faced sheep on this score has not been quantitatively evaluated but it is certainly important.

Inkster[3] reported that a very low lambing percentage in covered-faced two-tooth ewes accounted almost entirely for the low lifetime lambing percentage relative to open-faced ewes. The results of the present work show quite definitely that this suggestion is not true in our sheep in our environment for the differences were of the same magnitude at all ages.

The fundamental causes of face-cover effects, whether genetic or environmental, remain unsolved. Covered-faced ewes, while never becoming completely woolblind if eyewigged at the normal times, no

doubt have a limited vision in the weeks or months prior to eyewigging and shearing, and so may suffer from restricted feed intake. This could reduce lamb production, but it is difficult to see how it could at the same time increase wool production, which leads one to favour a genetic relationship between face cover and productivity. However it is known that light-rhythm contrasts affect both reproduction (Yeates[6]) and wool growth (Hart[7]). The reduced amount of light reaching the eye of covered-faced sheep or the suddenly increased amount received after eyewigging could conceivably cause a simultaneous decrease in reproductive rate and an increase in wool growth rate. This study is unable to throw any light on the matter.

As far as our present knowledge in relation to face cover goes, it seems obvious that on balance covered-faced sheep are at a definite disadvantage and should be culled. Relative to open-faced sheep they produce 23% less lamb and 3% more wool per sheep, or, it is suggested, 18% less lamb and 6% more wool per acre. The lamb effect is obviously more important than the wool effect even in fine-wooled sheep. One third of all the Corriedale sheep in our flock were graded as covered-faced and a similar proportion was obtained by Barton in the Massey College Romney flock. Hence the proportion of these lower-producing covered-faced sheep is high and the removal of these sheep could be an important contribution to improvement of the flock.

With regard to the intermediate-faced sheep, their lamb production is 7% less per ewe than the open-faced ones and the difference in wool production and bodyweight is very small. While the greatest and fastest gain will be obtained by removal of the covered-faced ewes, there still remains some advantage in going the whole distance, namely, in removal of the intermediate-faced sheep until ultimately the whole flock is open-faced.

Terrill and Hazel[8] have shown the heritability of face-cover to be high in Rambouillets, and we have reason to believe that it is also high in our sheep, so that straight selection of rams and ewes for open faces is a sufficient and strong method of attaining the desired improvement.

The speed with which this can be attained will be dependent largely on whether the stud breeders will recognize and act upon the need for open-faced sheep, since it is primarily through the supply of rams that improvement must come. It is suggested that the greatest encouragement to them in this direction would be stimulation of interest by grade sheep producers in the purchase of open-faced rams.

Acknowledgements

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A COMPARISON BETWEEN ROTATIONAL GRAZING AND SET STOCKING FOR FAT-LAMB PRODUCTION

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Summary

A series of trials is described in which, over the period of 5 to 6 months from lambing until weaning time, ewes and lambs were managed under a strict rotational grazing system and their productive performance compared with that of equal numbers set-stocked on similar areas of pasture.

At low and normal rates of stocking (4 to 6 ewes per acre) the rotational system was inferior in terms of lamb growth rate, while at the high rate of 8 ewes per acre it was superior. In no case was there any material difference in the ewes' wool production or live weight gain.

From observations made during the trials it is concluded that the rotational system made available more feed. Where feed supply was insufficient, this led to improved lamb growth; where feed supply was already adequate, the extra herbage caused an overall decline in the feed quality and resulted in poorer lamb growth.

Full realization of the potential value of rotational grazing requires an increase in stock numbers or conservation of the extra herbage for the future.

These results are consistent with those of previous experiments with dairy and beef cattle.

Introduction

Over the past seven years the nutrition of the breeding ewe and her fat-lamb progeny on grassland has been the subject of systematic study at Ruakura. The effects of different levels of pasture nutrition prior to and during the mating period[1] and during pregnancy[2] have already been studied. Attention has recently been directed to the period after lambing.

Most New Zealand farmers producing fat lambs run their ewes during pregnancy in fairly large mobs to ensure tight control of their grazing, but they generally prefer to set-stock the ewes and lambs from lambing time onwards. There is, however, a considerable amount of evidence that pasture yields are increased by spelling, and are further influenced by the length of the intervals, between grazings[3 to 12] though the conditions under which many of these experiments were conducted make it impossible to draw from them any direct inferences concerning the possible value of rotational grazing management on fat-lamb farms in New Zealand.

This paper reports three comparisons between daily rotational grazing and set stocking in the period from lambing to weaning time, i.e. August to January, each involving equal numbers of sheep run on equal areas of pasture. One trial used a stocking rate of four ewes, the second trial six ewes, and the third trial eight ewes, per acre. In the first two cases, cattle were grazed to control surplus pasture growth during spring and summer in the manner universally adopted by New Zealand farmers.

Material and Methods

Land: An area of approximately 54 acres was available, in eighteen 3-acre paddocks, each having access at one end to the roadway that

formed one edge of the rectangular area. Some paddocks were further sub-divided to provide at least six small paddocks for each rotationally grazed group.

The soil was a peaty loam on a sand and gravel subsoil and the land was capable of wintering six ewes per acre and fattening their lambs under good conventional management. The entire area had been topdressed annually for several years with 2 cwt. of superphosphate.

The pasture was very uniform and consisted of perennial ryegrass (*Lolium perenne*) and Yorkshire fog (*Holcus lanatus*) with a strong white clover (*Trifolium repens*). Minor constituents included browntop (*Agrostis*) and *Poa* species, crested dogstail (*Cynosurus cristatus*), and *Lotus major*.

Stock: Three hundred 5-year-old Romney ewes from hill country were used each year. They were mated to Southdown rams. Where necessary, 2- and 3-year-old Aberdeen Angus steers were used from October onwards to control surplus feed.

Details of Experimental Management

In 1951, the whole area was stocked with 6 ewes per acre. The week before lambing was due to begin, the flock and the area were both divided into equal, matched halves. One group of 150 ewes and their lambs was set stocked in nine 3-acre paddocks and the other group was rotationally grazed as soon as the lambs would follow their mothers, from 1 to 3 days after birth, on the remaining 9 paddocks. One cattle beast to 3 acres was run from October onwards in both groups.

In 1952, the area was divided in April after mating into twelve $1\frac{1}{2}$-acre paddocks stocked with 150 ewes (approximately 8 per acre) and twelve 3-acre paddocks stocked with 150 ewes (approximately 4 per acre). A few days before lambing started, each flock and each area was divided evenly in halves, one of which was thereafter set-stocked and the other rotationally grazed as in the preceding year. Both the 4-per-acre areas ran one beast to 2 acres from October onwards, but no cattle were needed on either of the areas carrying 8 ewes per acre.

Ewes that were to be set-stocked were placed in paddocks of "autumn-saved" feed initially and were sorted out, as pasture growth began, into freshening paddocks in which they remained until the lambs were drafted when about 4 or 5 months old.

Ewes to be rotationally grazed were picked up within 1 to 3 days of lambing into a single mob which was moved nearly every day to a fresh pasture. Until the spring growth came away, the mob was left for up to 3 days in each round on the dwindling reserves of autumn-saved pasture, but as soon as possible they were submitted to a regular daily change to which they very quickly became accustomed. It was necessary only to open the gate and attract their attention for the whole group to string quietly through the two gateways into their fresh pasture.

Measurements and Criteria for the Comparison

The ewes and lambs were weighed every 3 or 4 weeks, depending on the weather. This entailed a journey of about 300 to 400 yd. and generally no more than 40 to 90 min. absence from their paddock for

any group. Ewes were also graded for bodily "condition", i.e., degree of fatness, but these subjective data are not shown here.

At shearing time, the fleeces were weighed to 0.1 lb. and graded, and the staple length was measured.

The lambs were selected for slaughter by commercial pickers at dates determined by the season and the feed supply, but at the same time for each of the groups being compared. Thus, in 1951, the first killing was in mid-December for both treatments. In the 1952 trials, because of better-sustained pasture growth, the first killing was delayed until January 1953 for both pairs of groups. At slaughter, the carcass weights, measurements, and export grading were recorded, and stomach samples were taken from about half the lambs killed for an assessment of their parasite burden.

The experiments were terminated when the lambs were weaned at the time of drafting.

Comparison has been based on four criteria:

1. Growth curve of all lambs in the group.
2. The proportion of lambs selected by a commerical picker as fat at the drafting date.
3. The mean carcass weight and gradings of this draft.
4. The mean carcass weight and gradings of *equal* proportions of each of the two groups being compared.

The distinction between 3. and 4. is unimportant unless widely different numbers were killed in the two groups.

EXPERIMENTAL RESULTS

The three experiments will be called the Low-, Medium- and

TABLE 1. MEAN LIVE WEIGHT OF EWES (LB.)
(Number of ewes in brackets)

	Ewe Rearing			
	Single Lamb		Twin Lambs	
	Set-stocked (46)	Rotated (48)	Set-stocked (21)	Rotated (22)
End July (before lambing)	130	130	136	140
September	141	141	130	136
October	154	146	140	143
November	156	151	144	147
Mid January (after shearing)	137	135	125	133
Overall gain	7	5	—11	—7

High-stocking-rate trials respectively, and the results will be considered in this order.

Trial 1 (1952)—Low Stocking Rate: Four Ewes per Acre

It must be borne in mind that the live weight includes the fleece weight which is greatly affected by atmospheric moisture, and the weight of stomach contents which is greatly affected by feed quality and quantity, and by the time of weighing in relation to the sheep's grazing. For these reasons, no useful purpose is served by studying the minor points of difference shown above unless they are confirmed by other measurements.

TABLE 2. Fleece Weight and Characteristics
(Early January shearing)

Characteristic	Ewe Rearing			
	Single Lamb		Twin Lambs	
	Set-stocked	Rotated	Set-stocked	Rotated
Mean weight (lb.)	9.1	9.3	9.1	8.8
Staple length (in.)	5.6	5.5	5.4	5.5
Good to excellent (%)	22	31	5	15
Broken or cotted (%)	57	55	50	40

The differences between treatments were not significant.

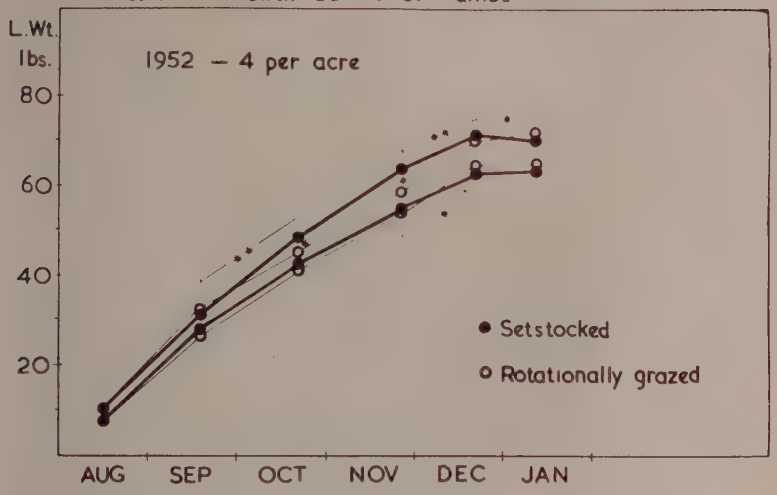
In general, it may be said that rotational grazing management did not noticeably affect the ewes in terms of overall live-weight gain or wool production.

In the preliminary analysis of these data, it was found that male lambs were consistently 5% to 10% heavier than females with no indications of interaction between sex and treatment. Since sex ratios in the experimental groups were similar, the weights of all single and of all twin lambs, irrespective of sex, are shown in the following growth curves, plotted against time, not against age. This latter point is discussed in a subsequent section.

Significance of differences in weight is shown by an asterisk in the usual way, and of differences in weight gain in a period by arrows and asterisks (Fig. 1).

The set-stocked single lambs gained more rapidly in September/October and established a difference of 3 to 4 lb. which they maintained until the end of November. The rotated singles then gained more rapidly and both groups had the same mean live weight in January. It is interesting to note that in October the set-stocked single-rearing ewes gained more weight than those rotationally grazed, while in November/January the latter caught up (Table 1).

FIG. 1 Growth Curves of Lambs



The twin lambs grew at closely similar initial rates, but the gain of the rotated twins was significantly greater than that of the set-stocked twins in December when the corresponding ewes also did better (Table 1).

The weight changes of the ewes, not themselves significant in a statistical sense, thus appear to be of practical significance, though it remains a matter for speculation whether these were genuine increases in body tissues or merely represented variations in the amount of food in the alimentary tract, resulting from changes in palatability and abundance of the pasture.

TABLE 3. LOSSES FROM BIRTH TO DRAFTING

	Set-stocked	Rotated
No. of lambs born alive	90	99
No. died from birth to 3 days	5	6
Accidental deaths	—	2 (drowned)
Tetanus after docking	2	—
Missing, fate not known	1	2
Total deaths	8	10
Alive at drafting	82	89

Tables 3 and 4 show no significant differences between grazing treatments. The differences between treatments in number of lambs born (90-99) and the differences in numbers reared (82-89) arose from the division of the flock before lambing, and from the subsequent random occurrence of multiple births.

TABLE 4. Drafting and Slaughter Data

Comparison of groups at 14 January 1953

	Set-stocked (82)	Rotated (89)	
No. drafted fat	53	(a) 62	(b) 58
Percentage	65*	70	65*
Liveweight	73.1	71.8	72.5
Carcass weight	34.5	33.1	33.6
Percentage graded:			
Down Cross	52	41	41
Prime	12	23	23
Second	1	6	1

*Comparison of same proportion from each group by selecting heaviest lambs in the rotated group.

General

In this trial neither single- nor twin-rearing ewes showed any evidence of a loss in physical condition or in true body weight over the lactation peak in August and September, and it may be assumed that the ewes were fed to their requirements for maintenance and full milk production over the whole experimental period. This provides a reasonable explanation of the very similar growth rates of twin lambs in both groups, for the early growth rate of twins is probably determined to a greater degree than that of single lambs by the ewe's milk production[13]. Under this lenient grazing and despite the use of normal numbers of cattle, the average feed quality on both the set-stocked and rotationally grazed areas declined somewhat over the experimental period as a result of a noticeable increase in Yorkshire fog, and a decrease in white clover, in the herbage. Ewes and lambs, particularly the latter, tend to graze selectively certain favoured areas or species while allowing the rest of the paddock to become rank[14] if they are offered more feed than they require. This uneven grazing occurred on the set-stocked areas but the rotationally grazed areas were grazed more uniformly. It is possible that the set-stocked single lambs grew better than those rotationally grazed because they were able to concentrate on part of their area and keep that down to sheep-feed length whereas the greater part of the rotational pastures became uniformly a little too long, though never as rough as the neglected parts of the areas set-stocked.

Trial 2 (1951)—Medium Stocking Rate: Six Ewes Per Acre

Again no importance is attached to short-term differences, but the overall gain of the single-rearing ewes of the two groups differed significantly ($P < 0.01$).

The differences between treatments were not significant though, as in Table 2, twin-bearing grew lighter and poorer fleeces than single-bearing ewes.

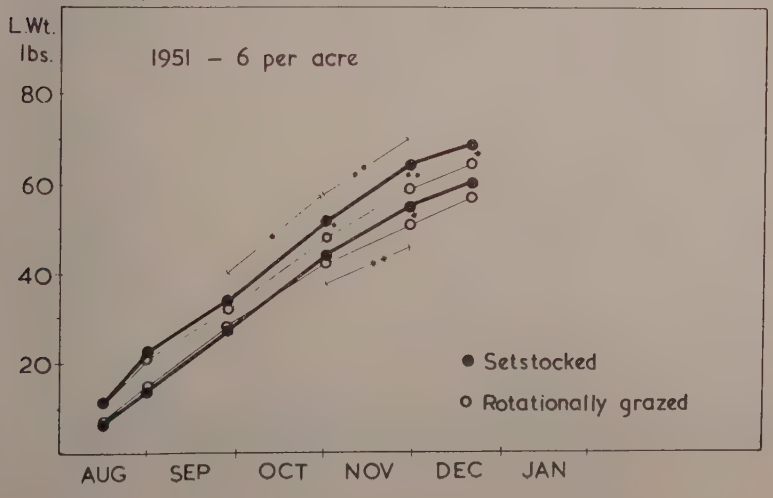
TABLE 5. MEAN LIVE WEIGHT OF EWES (LB.)
(Number of ewes in brackets)

Date	Ewe Rearing			
	Single Lamb		Twin Lambs	
	Set-stocked (97)	Rotated (98)	Set-stocked (25)	Rotated (29)
End July (before lambing)	123	123	129	127
September	125	120	114	115
October	132	127	121	122
November	142	135	132	129
Mid January (after shearing)	137	132	130	131
Overall gain	14	9	1	4

TABLE 6. FLEECE WEIGHT AND CHARACTERISTICS
(Late December shearing)

Characteristic	Ewe Rearing			
	Single Lamb		Twin Lambs	
	Set-stocked	Rotated	Set-stocked	Rotated
Mean fleece weight (lb.)	8.5	8.1	8.1	7.8
Staple length (in.)	4.9	4.9	4.8	4.8
Good to excellent (%)	17	15	—	5
Broken or cotted (%)	60	56	65	71

FIG. 2 Growth Curves of Lambs



Early rate of growth of all lambs seems to have been similar. During October and November, the set-stocked singles grew faster than the rotated single lambs and attained significantly higher live weights which were maintained until drafting time, 17 December 1951. The set-stocked single-rearing ewes, too, gained more weight over this period than those rotationally grazed.

Of the twin lambs, those set-stocked grew faster in November and their dams, too, gained better than the rotated ewes in this month.

TABLE 7. LOSSES FROM BIRTH TO DRAFTING

	Set-stocked	Rotated
No. of lambs born alive	171	178
No. died from birth to 3 days	11	10
Enterotoxaemia	5	2
Tetanus	—	3
Accidental deaths	4	2
Missing, fate not known	—	—
Total deaths	20	17
Alive at drafting	151	161

TABLE 8. DRAFTING AND SLAUGHTER DATA
Comparison of groups at 17 December 1951

	Set-stocked (151)		Rotated (161)
No. drafted fat	(a) 67	(b) 56	60
Percentage	44	37*	37*
Live weight	73.7	75.5	75.3
Carcass weight	34.7	37.3	32.5
Percentage graded:			
Down Cross	28	26	12
Prime	15	11	21
Second	1	—	4

*Comparison of same proportion from each group by selecting the heaviest lambs from the set-stocked group.

While the numbers fat did not differ greatly, the carcass weights and gradings favoured the set-stocked group.

General

Despite the nominal equality in numbers of stock on each area, there was a noticeable difference in the pasture available during much

of the spring. From October onwards, there was an abundance of feed for the rotationally grazed sheep but the number of cattle available was insufficient to control the growth completely. There was a clear change in the composition of the sward and a marked reduction in the white-clover content of all rotationally grazed paddocks. The set-stocked areas, on the other hand, never became out of control but maintained an excellent balanced pasture throughout the experimental period.

It is believed that the consequent decline in feed quality on the rotationally grazed area was largely responsible for the poorer performance of the rotationally grazed ewes and lambs in the later spring months.

Trial 3 (1952)—High Stocking Rate: Eight Ewes per Acre

TABLE 9. MEAN LIVE WEIGHT OF EWES (LB.)
(Number of ewes in brackets)

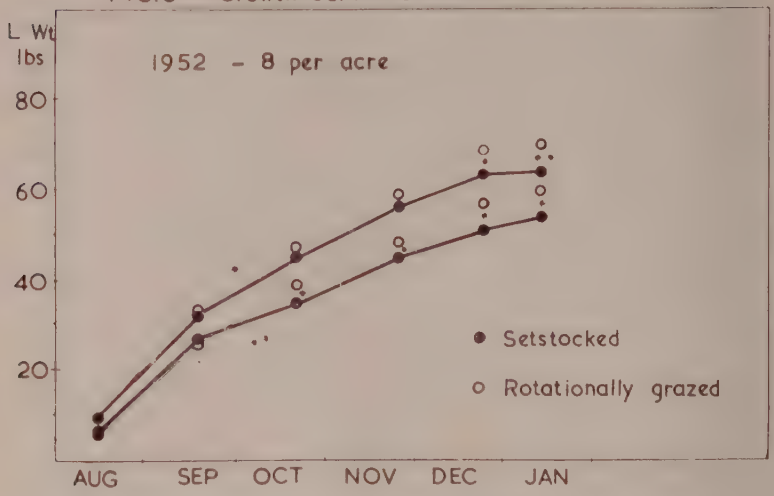
Date	Ewe Rearing			
	Single Lamb		Twin Lambs	
	Set-stocked (43)	Rotated (47)	Set-stocked (22)	Rotated (20)
End July (before lambing)	120	119	120	120
September	125	125	121	123
October	132	133	127	129
November	142	139	134	136
Mid January (after shearing)	127	125	120	121
Overall gain	7	6	—	1

TABLE 10. FLEECE WEIGHT AND CHARACTERISTICS
(Shorn early January)

Characteristic	Ewe Rearing			
	Single Lamb		Twin Lambs	
	Set-stocked	Rotated	Set-stocked	Rotated
Fleece weight (lb.)	9.1	8.6	8.8	8.4
Staple length (in.)	5.4	5.4	5.2	5.4
Good to excellent (%)	12	6	—	—
Broken or cotted (%)	47	56	74	70

Because of the variability in fleece weights and the small numbers of ewes involved, the difference between grazing treatments, though

FIG. 3 Growth Curves of Lambs



consistent, did not reach statistical significance. The difference between single- and twin-rearing ewes will again be noted, as in Table 2 and 6 previously.

In this trial, the rotationally grazed lambs grew more rapidly at all stages than the set-stocked lambs, the difference being particularly marked in the case of twins.

TABLE 11. LOSSES FROM BIRTH TO DRAFTING

	Set-stocked	Rotated
No. of lambs born	101	99
No. died from birth to 3 days	3	4
Enterotoxaemia	—	1
Accidental	2	2
Missing, fate not known	3	2
Total deaths	8	9
Alive at drafting	93	90

Considerable difficulty was experienced in this trial in keeping ewes and lambs in the correct paddock and group and two set-stocked lambs listed above as missing were later found alive in another flock on rather more attractive pasture.

As might be inferred from the growth curves, the set-stocked lambs were a poorly grown line at the end of the experimental period, significantly lower in live weight, and in the carcass weight and grading of those killed.

TABLE 12. DRAFTING AND SLAUGHTER DATA
Comparison of groups at 14 January 1953

	Set-stocked (93)	Rotated (90)	
No. drafted fat	29	(a) 41	(b) 28
Percentage	31*	46	31*
Live weight	68.7	72.6	75.4
Carcass weight	31.6	33.1	34.9
Percentage graded:			
Down Cross	16	30	25
Prime	13	13	6
Second	2	3	-

*Comparison of same proportion of each group by selecting heaviest lambs from rotated group.

General

In this trial, both groups were very short of feed just after lambing. Regrowth was strikingly better on the areas alternately grazed and spelled for 5 to 6 days than on those set-stocked. From their bad start, the latter paddocks never recovered but remained uniformly bare throughout the period of spring growth. From mid October onwards, the rotationally grazed paddocks showed a good cover of excellent pasture, indeed for the rest of the experimental period the field from which the rotated group had just been shifted still contained more abundant and far more attractive feed than the adjacent set-stocked paddocks.

Surprisingly, the ewes of the two groups did not differ in live-weight at any stage (Table 9) despite the apparently much better level of nutrition of the rotationally grazed group, and the better growth of their lambs. This is perhaps best interpreted as evidence that the set-stocked ewes managed to satisfy their needs for body maintenance and production despite the sparseness of the feed, but in so doing kept the pastures so short that the lambs could not obtain enough grass to sustain their initial growth rate derived from milk alone.

If this is correct, the curves of Figure 3 suggest that, while the growth of twins may, in general, be more directly restricted than that of singles in the early weeks of life by the ewe's milk production, the growth of twins from the second month onwards was more impaired by restriction of the quantity of pasture they could obtain than was that of the single lambs.

General Points: All Trials

Ewe Losses

In each of the smaller groups (low and high stocking rate trials —75 ewes) from one to three ewes died during the spring, from causes not related to their experimental treatments. From the larger groups

(medium rate—150 ewes) five and six ewes were lost from post-lambing infections, accidents, and persistent vaginal eversion (one case). These cannot be ascribed to grazing management.

Cattle

In neither the 1951 nor the 1952 trial was there any material difference between the two treatments in the weight gains of the steers or in the numbers fattened off during the season.

Lamb Parasite Burdens

The following figures were obtained from examination of the random selection of 20 to 25 lambs from the draft killed at the end of the experimental period in each group:

TABLE 13. Worm Counts (Geometric Means)

Species	Low Rate		Medium Rate		High Rate	
	S	R	S	R	S	R
Haemonchus	10	24	27	110	22	34
Ostertagia	600	500	1500	2100	1700	700
Trichostrongylus axei	—	—	174	77	—	—
Nematodirus	600	200	2800	3100	600	300
Trichostrongylus spp.	200	300	800	500	1600	700
Cooperia	300	300	400	300	1500	300
Strongyloides	1100	400	600	500	1100	700
Bunostomum	3	3	—	—	5	2
Trichuris	2	2	14	37	1	1
Oesophagostomum	—	—	1	1	1	—
Chabertia	12	7	11	16	7	4

There is evidence of slightly more *Haemonchus* in the rotational groups in all trials, but differences in other species were inconsistent. All were low-level infestations.

Discussion

In field trials of this nature, a number of inter-related pasture and animal factors combine to affect the final performance of the stock.

The growth-rate of lambs depends on their initial weight, their milk consumption, and increasingly on their direct intake of pasture herbage. We do not know whether, as a consequence of their lower milk intake[13, 15], twin lambs start to graze earlier in life than do single lambs, nor whether at any given age they consume a greater proportion of their intake directly as grass. We therefore do not yet know under what conditions, or for what period, it is better to provide the ewe with abundant feed of good average quality to sustain high milk production,

than to provide rather less feed but of the very highest quality primarily to suit the lambs.

It is clear, however, that in grassland farming, the use of a system of stocking or grazing which provides an over-abundance of feed involves the risk of a decline in its average quality which the stock will endeavour to counter by some degree of selection—either by selecting the choicest species from the entire pasture or by confining their grazing to favoured areas which they can keep short and sweet. In many cases, their total feed intake is likely to decrease, and the extra energy cost of this type of grazing must, in any case, reduce their useful production even if the gross feed intake were maintained. The decline in palatability which probably accompanies such an increase in total herbage may be of particular importance to the lambs, and any increase in a ewe's milk production resulting from greater feed supply may be more than offset by a reduction in the lamb's direct intake of pasture nutrients.

These or similar interactions are suggested as possible reasons for the results reported here.

If the regular shifting involved in rotational grazing had itself been harmful to the lambs, that fact should have been evident within the first few weeks of the trials when the lambs were youngest, most easily mismothered, and most dependent on milk for their growth. This was not the case, for most of the differences in growth rates occurred at later stages of the season when they could most logically be ascribed to the changes that had by this time become apparent in the pastures. This, too, is the reason for showing curves (figures 1–3) of lambs' weight as a function of date rather than of age. Since lambing lasted a month, the latter method of plotting would tend to obscure effects associated with time.

The general picture of pasture and animal response thus seems consistent with the subjective observation that more feed became available on the areas rotationally grazed, though it must, in the meantime remain a matter for speculation whether this was due to more rapid pasture growth or resulted from more economical use of the feed available earlier, which thus accumulated as a reserve ahead of the flock.

The present trials support most of the findings previously reported—that rotational grazing methods increase the amount of feed available, and should be capable of giving substantial increases in total output per acre, primarily by an increase in carrying capacity and not by increasing production per head[16] except where this was previously limited by the amount of feed available.

On leniently stocked fat-lamb farms the problem is one of controlling the spring flush of pasture, and continuous grazing is the easier way to achieve this.

The value of rotational grazing in spring and early summer is thus doubtful except where farmers are prepared to increase stock numbers appreciably to graze the extra feed, or can harvest it as hay or silage to augment their wintering capacity and thus obtain higher annual output per acre.

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ROOT DEVELOPMENT IN SOME COMMON NEW ZEALAND PASTURE PLANTS

VII. SEASONAL ROOT REPLACEMENT IN PERENNIAL RYEGRASS (*Lolium perenne*) ITALIAN RYEGRASS (*L. multiflorum*) and TALL FESCUE (*Festuca arundinacea*)

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Summary

Roots have been classified as "white" and "other than white" roots. The importance of the former is stressed.

New "white" roots are produced following germination and again when root growth re-starts in autumn following a period of little or no activity in summer. New roots are initiated from early autumn at an increasing rate until late in winter; the rate of initiation then declines.

The use of 2,3,5-triphenyl tetrazolium bromide as an indicator of viable root tissue was successful, but further study is needed to work out a satisfactory technique.

Italian ryegrass roots differed from those of perennial ryegrass and tall fescue in four characters. Each of these characters could operate against the survival of Italian ryegrass plants.

A hypothetical annual replacement rate of roots is advanced.

Introduction

"Of the dry tissue of a plant only about 10% comes in through the roots; the remaining 90% is derived from the air through the leaves which, quantitatively, are of very much greater importance as nutritional organs than are roots." This statement by Melville (1954) does not indicate that the root system has little importance in obtaining food. Plant requirements for inorganic foods are at high levels in productive pastures and their uptake is through the roots. To a great extent, the 10% of the dry tissue taken in by the roots serves as a pacemaker for the level of activity that produces the remaining 90%. For vigorous leaf production and activity, there must be a vigorous root system capable of fully meeting the plants' nutritional needs.

It has become increasingly apparent during the course of root studies at this centre that the ageing of grass roots can take place rapidly and that the onset of senility may become evident within a few weeks. As the bulk of the available mineral food and nitrogen is to be found in the upper rather than the lower levels of the soil, it is clear that new root formation fits into the pattern of growth in a simple manner. The new roots with their vigorously absorbing surfaces pass through the more fertile upper soil zone into the subsoil and then down to a depth where available food is low and where it is surmised they function primarily as suppliers of water.

With the advance in senility there occurs a change in colour of the root epidermis, the degree of change varying with the species but present in all of those examined. In perennial and Italian ryegrass and tall fescue, the bulk of the new roots first appear as thick glossy "white" roots (Jacques 1935), but become darker with age until they may assume a

light, medium, or even dark brown colouration. Coincident with this darkening there is a development of tenderness and an ultimate sloughing of the cortical tissue from around the stele. Thus the root mass at any one time will consist of young "white" roots and roots "other than white" that are in various stages of the ageing process. There is considerable variation in the roots of any one plant and between plants in the amount of cortex sloughing, and it has not been found feasible to use this factor in any comparative way. The two main divisions of the root system for the purpose of this paper are (1) "white" roots and (2) roots "other than white". It is admitted that this division represents an over-simplification of the problem of root classification, but the object in this trial is to be able to recognize root replacement under conditions of normal growth without the artificial experimental conditions imposed in a previous trial (Jacques and Edmond 1952). It can be said at the outset, however, that a comparable result has been obtained in these two trials. The present trial has allowed a study of the behaviour (including root initiation and deterioration) over a 12-month period of the total root systems of three grass species.

Review of Literature

While the literature on the seasonal behaviour of leaf and shoot growth in grasses is plentiful, much less is known of the seasonal behaviour of roots. Sprague (1933) attempted to relate the seasonal root development of 5-year-old stands of *Poa pratensis* and *Agrostis vulgaris* to soil conditions. He found that the maximum root weight in both species was about twice that of the quantity present at the start of the season and concluded that at least one half of the root system is newly generated each spring. Stoddart (1935) showed that banded roots lived for at least one year and many for much longer. Roberts and Hunt (1936) showed that, in perennial ryegrass, root weight increased in spring and summer and decreased as plants produced flowers. Stuckey (1941) using mitosis as the criterion of root growth found that root-tip cells were dividing actively at around 32°F. while cessation of root growth during summer coincided with periods of high soil temperatures. She found that in 6 grasses, including perennial ryegrass, the whole root system was regenerated annually, new growth commencing in autumn and rapidly increasing in spring. *Poa pratensis,* cocksfoot, *Poa compressa,* and *Agropyron cristatum,* produced only a few new roots after the first spring and only a small percentage of roots disintegrated. Jacques (1943) found two periods during the sampling times when root weights decreased in perennial ryegrass; the first of these occurred during June and July and was of small dimensions, but the cause was not determined. The second period, which followed a rapid increase in root weight lasting till the end of November, extended from then to the end of February and it was found to be due to root mortality and sloughing of the cortex. Weaver and Zink (1946) working with 10 perennial grass species found a high rate of root survival over at least the first 12 months, while some roots remained alive for fully 3 years. Jacques and Edmond (1952) have shown that the maximum production of herbage coincided with low root initiation and this was more marked in perennial ryegrass than in cocksfoot. Troughton (1951) found that in old pastures in Wales the amount of root material was lowest in November with a consistent increase until May or June followed by a gradual decrease, which was partly due to root death and decay, from July to November.

Materials and Methods

Four grass species were selected for trial. *Lolium perenne* and *L. multiflorum* were selected as being long and short-lived members of an economically important genus in this country. *Festuca arundinacea* was included, not as a pasture plant but because of its marked persistency and *Poa annua* because of its ephemeral life cycle, but the latter was excluded from the results because of the high mortality of plants early in the trial.

Plants were grown in glazed cylindrical pipes 1 ft. in diameter and 1 ft. long sunk into the soil so that the sides were vertical and the rim remained ½ in. above ground level. A uniform silt loam was used to fill the pipes to within ½ in. of the top and, on 12 August 1952, all pipes were labelled and a mixed fertilizer consisting of 2 parts superphosphate, 1 part bonedust, and 1 part dried blood, was applied at the rate of 12 g. per pot (13 cwt. per acre) and mixed with the top inch of soil. No further fertilizer application was made.

Plants raised from seed which had been sown in seed-boxes in a warm greenhouse and hardened off in a cold frame were planted into the pipes on 13, 14, and 15 August, and watered. The seedlings were watered on four subsequent occasions, the last on 30 September. The trial season was wetter than the 25-year average rainfall by 22%, and 55.38 in. of rain were recorded between 17 September 1952 and 16 November 1953.

Nucleus stock seeds of perennial (Ba 40 1950/51) and Italian (Bb 408 1951/52) ryegrass were supplied by the Grasslands Division, Department of Scientific and Industrial Research and while not genetically uniform were as homogeneous as any that could be obtained. Seeds of tall fescue were hand collected from an isolated group of plants, and *Poa annua* seeds were provided by the Seed Testing Station, N.Z. Department of Agriculture.

The plan of replication was based on Edmond's figures (1949) which were derived from clonal plants. It was assumed that the species used in the present experiment would show differences of the same magnitude as found by Edmond. Consequently eight plants of each species should allow a detection power in the statistical analysis of approximately 25% of the mean of the measurements for all plants of all species taken at any lifting. Two pipes with 4 plants in each would thus be required for each species at each lifting necessitating the examination of a block of 8 pipes (including the subsequently discarded *Poa annua* pipes) in each lifting. There were sufficient pipes available to allow 17 blocks to be laid down and raised for examination at 3-weekly intervals.

Results

Staining Pattern with Tetrazolium Salt

Results of preliminary work on roots of *Poa annua* indicated that a 1% concentration of 2,3,5-triphenyl tetrazolium bromide in distilled water was capable of staining certain root tissues. This is the same concentration that is recommended for use in testing the viability of seeds (Hyde 1949). Adequate staining resulted from root immersion in the solution for 8 hours at 30°C. in the dark, and longer periods did not give any clearer staining pattern. Root tissues that had been killed with boiling water did not stain.

The root tip and approximately 1 mm. of root immediately behind it stained a dense red colour and young emerging laterals up to $\frac{1}{8}$ in. in length showed a similar dense red staining, indicative of an oxidative capacity of the tissues. Older lateral roots showed this intense staining only in the region near the tip. The stained regions coincided with the 4 regions in the growing tip defined by Goodwin and Stepka (1945) for timothy.

The vascular cylinder stained consistently over its entire length, but the intensity of colour was never so great as at the tips. The cortex failed to stain or at most presented a very pale pinkish colouration.

When this stain technique was applied to the tall fescue and the two ryegrasses in this trial, similar staining patterns were obtained, i.e. the root tips turned a deep red, the vascular cylinder a less intense red, and the cortex a pale pink. The vascular cylinder, even after the cortex had sloughed off, still stained, suggesting that loss of cortical tissue did not interfere with the functioning of the stele as a conductor of water and solutes from the distal portion of the root. As the root tissues darkened with age, it became increasingly difficult to recognize the red formazan precipitate, and, at the lifting on 1 and 22 June and on 13 July, no consistent staining pattern could be detected with the naked eye, but was discernable when a low power ($\times$ 12) binocular microscope was used. After 13 July, tetrazolium staining was discontinued, since the older root tissues were so dark that satisfactory descriptions of the staining pattern could no longer be made. This method shows promise as a means of further investigating root senescence, but a satisfactory technique has still to be worked out.

Sonnenblick *et al.* (1950) reported that formazan deposited in sectioned onion roots began to diffuse out of the cells some 1 to 2 hours after the start of a test. It has been suggested by Stafford (1951) that selective absorption by certain tissues may be involved in the apparent localization of reduced tetrazolium salts. Goodewaagen (A. Troughton pers. comm.) has used tetrazolium chloride in an attempt to distinguish between respiring and non-respiring roots, but found that only young white roots respired with sufficient rapidity to produce colour change.

Growth-behaviour Patterns in Roots

While colour has been the principal means in this trial of differentiating the two root classes, the condition of the cortex also alters as the roots pass from "white" to "other than white". A tenderness develops and ultimately the cortex sloughs. Tenderness and commencement of sloughing in the cortex of Italian ryegrass roots were recorded 4 weeks earlier than in the other two species.

Numbers of "White" Roots per Plant. It is clear from previous work (Jacques and Edmond 1952), and from the present trial, that root initiation varies with the season of the year. The bulk of the nodal roots start as "white" roots and assume a dark colouration with age.

With the resurgence of growth in autumn it became feasible to differentiate by colour alone the newly formed roots from those that had been produced previously and termed "other than white" roots. It was then possible by recording the number of "white" roots at different liftings to relate them to the root system as a whole to ascertain the

pattern of root behaviour throughout the year. That numbers varied significantly through the year is shown in Table 1.

TABLE 1. ANALYSIS OF VARIANCE FOR NUMBERS OF "WHITE" ROOTS PER PLANT

	Sums of Squares	Degrees of Freedom	Mean Square	F Value	F Required 0.05	F Required 0.01	Result
Dates	124325.7	12	10360.5	3.89	2.18	3.03	**
Species	21163.3	2	10581.7	3.97	3.40	5.61	*
Dates × Species	63950.2	24	2664.6	5.38	1.56	1.86	**
Residual	128876.5	260	495.7				
Total	338315.7	298					

In perennial ryegrass, the numbers of "white" roots recorded per plant started with their first differentiation from "other than white" roots on 9 March with an average of 21.8. During April and May the numbers increased to between 40 and 50 per plant and this figure was maintained through June and rose to a peak of 64 in mid July. From then on there was a steady decrease until the final lifting in mid November when there were only 4 per plant.

In Italian ryegrass there were 6.6 per plant on 9 March followed by a steady increase to 127.4 on 13 July. The numbers remained at between 90 and 100 during August but thereafter declined steadily at each successive lifting, and at the final lifting in mid November there were only 8.4 per plant.

In tall fescue, there were 21.1 "white" roots per plant on 9 March, but here the numbers did not show the steady increase and later decrease shown by the ryegrasses. Over 8 liftings, a mean value of between 20 and 30 white roots was maintained, and only 5 liftings gave values outside this range. In common with the ryegrasses, the number in mid November was low (4.4).

There were 3 important trends evident from Fig. 1.

(1) The "white" root formation in Italian was slower to start than in perennial ryegrass or tall fescue and did not reach high levels until May.

(2) "White" root formation in Italian was approximately double that in perennial and about 3 times that in tall fescue during the peak period of July and August.

(3) "White" root formation in tall fescue was at a fairly steady level from March till October with increases in July and September and remained fairly high in October. This pattern contrasts with those in the ryegrasses, where increases to a peak in July were followed by decreases to low values by the end of October.

Numbers of Roots "Other than White" per Plant. It should follow that roots "other than white" conform to the pattern of the "white" roots

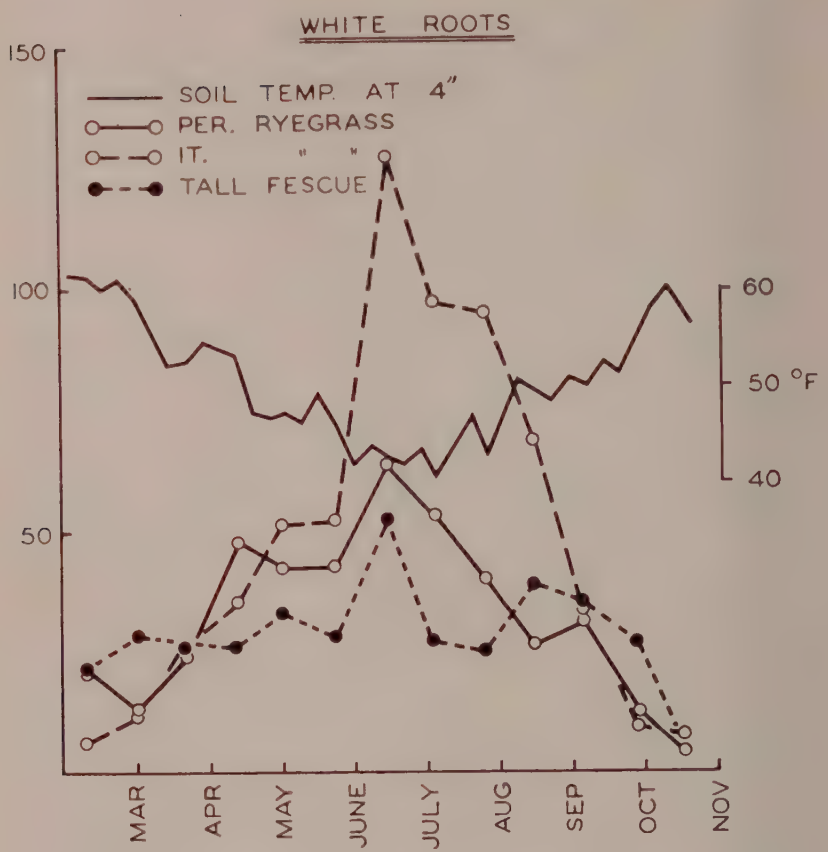

Fig. 1.—Numbers of "white" roots per plant, and soil temperatures (°F.) at 4 in.

if there is a uniform root-growth and survival rate. The pattern however will be modified by the rate of senescence and influenced by the rate of mortality and decay. In perennial ryegrass the peak of "white" root production was in July while the peak of the "other than white" roots was in October. The lowest number of "other than white" roots coincided with the peak of "white" roots. The same held good for Italian ryegrass, but in tall fescue the pattern was different in that fewer "white" roots were initiated, while the root replacement rate and onset of senescence were slower.

Total Numbers of Roots per Plant. 1. Perennial ryegrass. The numbers of roots per plant were consistently greater in perennial ryegrass than in the other two grasses until the last two liftings, and the trial finished with the numbers approximating those of tall fescue. There was a declining trend from March with 400 roots per plant to November with 260. Senescence during this time was taking place rapidly and was in excess of the rate of new root formation. There were periods with high and low root numbers, for example the numbers were high at

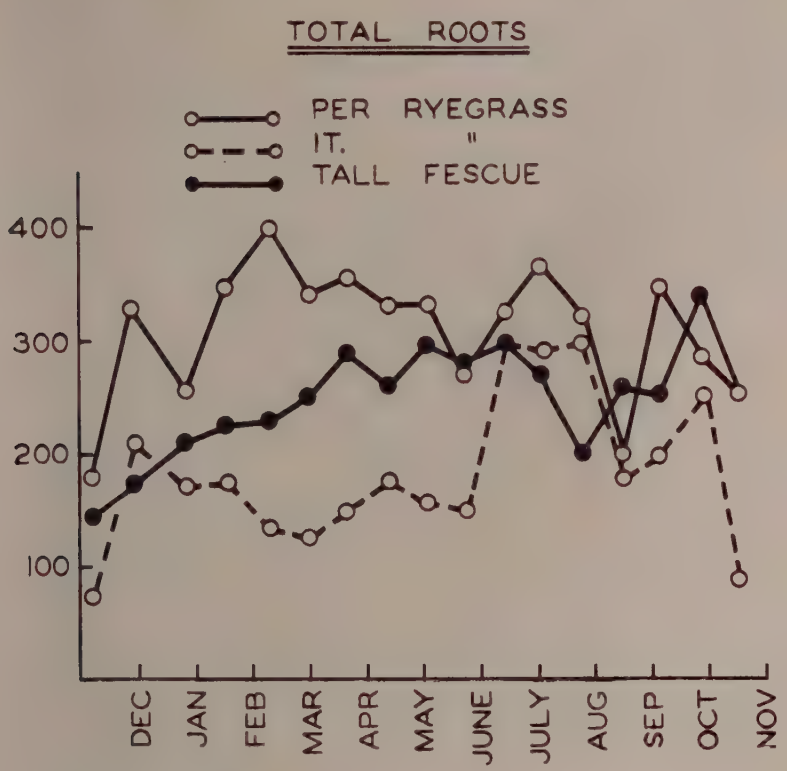

Fig. 2.—Total numbers of roots per plant.

the end of July and in early August and also in early October, and low in June and September. These peaks are not fortuitous, as a somewhat similar pattern was found in Italian ryegrass during the same periods. A low value in June for root weight had previously been noted in perennial ryegrass by Jacques (1943).

2. Italian ryegrass. During January and extending to the end of March, there was a decline in root and tiller numbers. This may be due to the relatively short effective life of Italian ryegrass roots, together with a cessation of new root initiation. The rapid senility without root replacement would make it impossible for the number of tillers (which were developed during a period when new roots and tillers were being formed rapidly) to be maintained.

At the end of March, Italian ryegrass had an average of 125 roots per plant. The numbers increased to 175 by mid May, declined to 150 in June, and reached a maximum around 300 between mid July and the third week in August. They dropped to under 200 in mid September, rose to just over 250 at the end of October and stood at a little below 100 at the end of the trial in mid November.

3. Tall fescue. In March, tall fescue had an average of 232 roots per plant and the numbers increased steadily to 300 in mid July. The

slump in the root numbers that was evident in the ryegrasses in mid September occurred near the end of August, i.e. three weeks earlier in tall fescue and was followed by a very marked and rapid increase to a peak of 342 roots per plant at the end of October. There was less evidence of a marked slump in June than in the ryegrasses.

Root Dry-matter Percentages

The differences between the "white" and the "other than white" roots so far has been based on colour, together with condition of the cortex and the staining pattern. In addition, fresh and oven-dry weights were available for the 2 classes of roots for each individual plant from

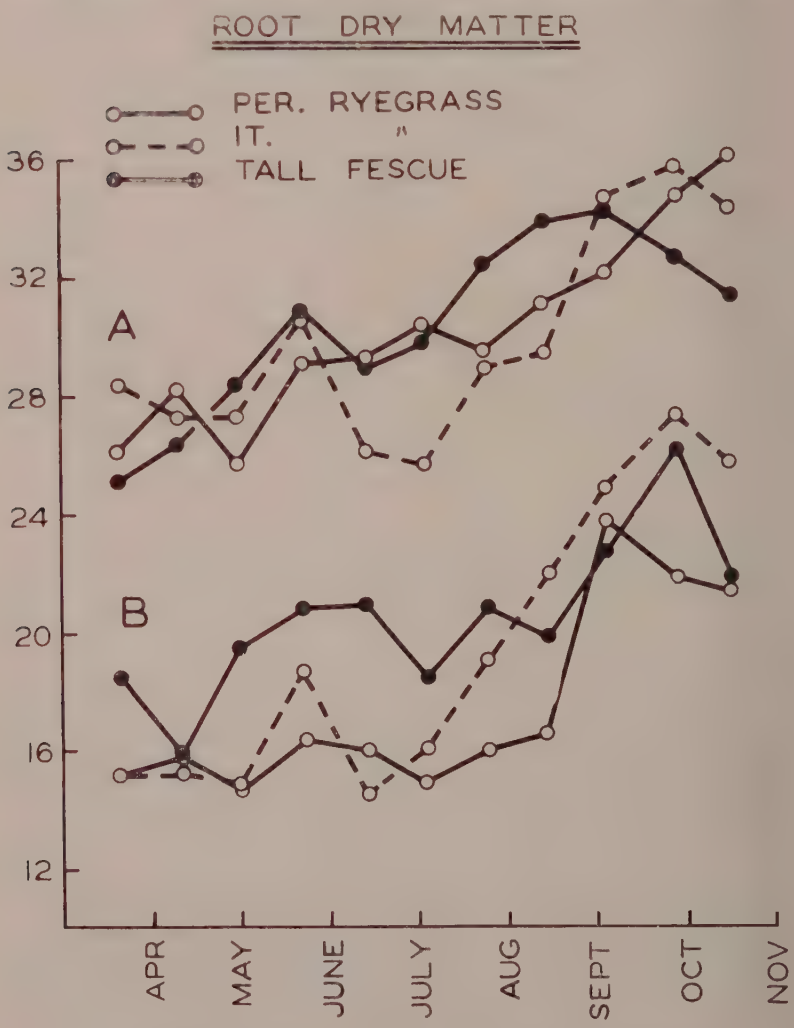

Fig. 3.- Mean percentages of dry matter: A. "Other than white" roots. B. "White" roots.

20 April until the end of the trial in November. The mean values for dry-matter percentage for each species at each lifting are shown in Fig. 3. For each species it can be seen that the "other than white" roots had a dry-matter content some 10% higher than that of the "white" roots and this difference in each species is significant at the 1% level. The reason for the increase in the dry-matter percentage from April to October and the fall in November has not been ascertained.

Further evidence of differences between the "white" and "other than white" roots became available from analyses of crude fibre. Bulked dry samples from liftings on 13 July, 3 August, and 27 October were analysed for crude fibre and the results are given in Table 2.

TABLE 2. PERCENTAGE OF CRUDE FIBRE IN ROOTS

	Perennial Ryegrass	Italian Ryegrass	Tall Fescue
"White" roots	35.2	34.3	32.6
"Other than white" roots	42.1	38.4	43.1

While these crude-fibre percentages were made as single determinations and are therefore likely to contain concealed errors, they show that for each species the crude fibre of the "white" roots is at least 4% less than that of the "other than white" roots. This is consistent with "white" roots being composed of younger tissue and suggests that they may be more concerned in the absorption, storage and conduction of metabolites than as anchors for the plant.

Numbers of Roots per Tiller

"White" Roots. The three grasses under study exhibited different patterns in the numbers of tillers per plant and the number of "white" roots per plant. A combination of these two counts to give the number of "white" roots per tiller may therefore show the importance of newly formed roots to the essential units in the pasture population, i.e. the individual tillers (Mitchell 1954). "White" roots were more numerous around the periphery of the plant where the majority of the new tillers were being produced, but the development of new "white" roots was not confined to new tillers.

An analysis of variance showed that there were highly significant (1% level) differences between both dates and species and that there was a highly significant interaction between dates and species. This interaction has been elucidated further; separate analyses of variance for each lifting date have been calculated and the results presented in Table 3.

From early April until the middle of October, the number of "white" roots per tiller was significantly greater in Italian than in the other two grasses. There was a similarity between the numbers of "white" roots in perennial ryegrass and in tall fescue.

TABLE 3. ANALYSES OF VARIANCE FOR NUMBERS OF "WHITE" ROOTS PER TILLER

Date	Means			Standard Errors of Means		F Values			Result	Difference Required between Means for Significance	
	Perennial Ryegrass	Italian Ryegrass	Tall Fescue	Perennial Ryegrass Tall Fescue	Italian Ryegrass	Actual	0.01	0.05		0.01	0.05
9 Mar.	0.15	0.21	0.41	± 0.06	± 0.06	4.83	5.78	3.47	*	0.24	0.18
30 Mar.	0.10	0.50	0.47	± 0.10	± 0.11	5.15	5.93	3.52	*	0.39	0.28
20 Apr.	0.22	0.79	0.47	± 0.11	± 0.11	6.89	5.78	3.47	**	0.44	0.32
11 May	0.32	0.65	0.37	± 0.07	± 0.07	6.81	5.78	3.47	**	0.27	0.20
1 June	0.39	0.97	0.46	± 0.07	± 0.08	17.21	5.93	3.52	**	0.28	0.21
22 June	0.40	0.82	0.30	± 0.06	± 0.06	20.22	5.78	3.47	**	0.24	0.18
13 July	0.48	1.11	0.53	± 0.04	± 0.05	56.12	6.01	3.55	**	0.16	0.12
3 Aug.	0.40	0.88	0.30	± 0.08	± 0.10	10.86	6.01	3.55	**	0.32	0.24
24 Aug.	0.32	1.00	0.32	± 0.10	± 0.10	15.52	5.85	3.49	**	0.39	0.28
11 Sept.	0.36	1.02	0.51	± 0.07	± 0.08	19.42	5.93	3.52	**	0.29	0.21
5 Oct.	0.27	0.63	0.39	± 0.08	± 0.09	4.48	5.85	3.49	*	0.32	0.24
27 Oct.	0.19	0.13	0.36	± 0.05	± 0.05	6.79	5.78	3.47	**	0.18	0.13
16 Nov.	0.05	0.30	0.06	± 0.04	± 0.04	14.77	5.85	3.49	**	0.14	0.10

Roots "Other than White" per Tiller. These figures were derived from the number of tillers per plant and the number of roots "other than white" per plant. The value of these derived figures is limited, as there is no information on the degree of variability in the numbers of roots associated with older tillers and newly formed ones entering upon the active cycle of growth. An analysis of variance for the data obtained, however, showed that there were highly significant (1% level) differences between the number of roots "other than white" per tiller over the various lifting dates and between the three species, and a highly significant dates × species interaction.

Results from separate analyses of variance at each lifting date showed that there was a degree of inter-specific variation in the average number of roots per tiller. Up to mid March the number was too variable to show any regular trend. From late March to mid August tall fescue consistently had more roots per tiller than either of the ryegrasses. From late August there were no differences detectable on the data available.

Two periods can be recognized when there was some difference between the two ryegrasses in the numbers of roots "other than white" per tiller. From mid February to the end of March, Italian ryegrass had more roots per tiller than perennial. From 1 June until mid September, Italian ryegrass had consistently fewer roots per tiller though the differences were not always statistically significant.

Total Roots per Tiller. It is clear from Table 4 that there are two periods when roots per tiller were high, i.e. in April when autumn growth

TABLE 4. MEAN NUMBERS OF ROOTS PER TILLER

Date	Perennial Ryegrass			Italian Ryegrass			Tall Fescue		
	Other than White	White	Total	Other than White	White	Total	Other than White	White	Total
9 Mar.	2.82	0.15	2.97	3.54	0.21	3.75	4.22	0.41	4.63
30 Mar.	2.26	0.10	2.36	3.71	0.50	4.21	3.62	0.47	4.09
20 Apr.	3.50	0.22	3.72	3.30	0.79	4.09	4.72	0.47	5.19
11 May	2.06	0.32	2.38	2.60	0.65	3.25	3.70	0.37	4.07
1 June	2.53	0.39	2.92	2.05	0.97	3.02	3.78	0.46	4.24
22 June	2.06	0.40	2.46	1.70	0.82	2.52	2.92	0.30	3.22
13 July	2.03	0.48	2.51	1.45	1.11	2.56	2.52	0.53	3.05
3 Aug.	2.10	0.40	2.50	1.86	0.88	2.74	3.12	0.30	3.42
24 Aug.	2.29	0.32	2.61	2.15	1.00	3.15	2.19	0.32	2.51
14 Sept.	2.49	0.36	2.85	2.04	1.02	3.06	2.89	0.51	3.40
5 Oct.	2.59	0.27	2.86	3.00	0.63	3.63	2.47	0.39	2.86
27 Oct.	3.72	0.19	3.91	3.64	0.13	3.77	4.28	0.36	4.64
16 Nov.	3.12	0.05	3.17	3.07	0.30	3.37	3.13	0.06	3.19

was under way and in September when spring growth was becoming pronounced. The autumn (April) peak found in all three grasses would appear to be due to tiller mortality and not to any spectacular production of new roots (which would be under the "white" root classification). In fact, the high figures in April formed the commencement of a period of high root initiation through the winter and followed a slump period of new root production through the summer. The high figures therefore can only indicate that tiller mortality has occurred, and that roots from dead tillers have been included in the total and this has boosted the mean number per tiller.

The spring peak was quite different. It followed a period when tillers were tending to decline and root numbers were increasing and represented the accumulation of roots developed during the winter whose rate of production has ultimately exceeded the rate of root decay.

The make-up of the root system of Italian ryegrass emphasizes the importance of "white" roots to the plant, and in 12 of the 13 counts the numbers per tiller were higher than in perennial ryegrass and in 11 were higher than in tall fescue.

DISCUSSION

In any plant material there exists a degree of variability due to genetic and environmental forces. In this trial, 8 plants of each species were examined at each lifting in an attempt to minimize the effects of this variation. In most of the analyses of variance made there was a satisfactory level of significance despite fairly high standard errors.

The technique adopted was of sufficient precision to enable certain trends to be noted and a comparison made between the roots of the three grasses under the conditions of this trial. It is fully realized that conditions differ considerably from those that exist in a mixed pasture sward. The exclusion of inter- or intra-specific competition, the absence of clovers, and the lack of grazing with all that this implies, has introduced a feature of artificiality but has secured a greater degree of uniformity in defoliation and general growth

A distinction has been made between the "white" roots (Jacques 1935) and the "other than white" roots. The "white" roots are readily distinguished by colour and cortex condition and represent the degree of new root initiation. That there is a warrantable distinction between them is disclosed by the dry matter content and the crude fibre content which are consistently lower in the "white" roots. Loss of cortical tissue was first observed in these trials in early March. This is later than found by Yen (1947) and Jacques (1941). This could be accounted for by late planting into the pipes (i.e. younger plants) and a wetter-than-average season (9 inches of rain in January). Visible deterioration of the absorbing surface as evinced by a sloughing of the cortex in older roots of plants from autumn-sown seed normally begins with the approach to maximum top (herbage) growth in late spring.

The fact that root stelar tissue stained with tetrazolium salt throughout its entire length, even after the loss of some of the cortex had led to exposure of the stele, indicates continued activity in such roots. The feeding areas are restricted to the distal portions of the root and to the lateral roots that have developed in this region and possibly also to the secondary root tissue adjacent to the point of attachment (Jacques 1939). The stele merely serves as a conducting channel for water and solutes to the aerial portions of the plant. It can be concluded that despite loss of cortex in the upper portions of the older roots during summer and autumn, which impairs the absorbing capacity of roots in the upper soil layers, they are still functioning in the lower depths.

The more intense staining of root tips suggests high biological activity there. The tetrazolium staining method offers a convenient means of determining if roots are alive and active, but requires further study.

Root Numbers and Weights

Root numbers have been taken as a basis of differences between these three grasses as they lead to more consistent and more discerning conclusions than root weights. Both root numbers and root weights were analysed statistically and showed a similar pattern. More precision was obtained however from the analyses of variance based on numbers as against weights; for example, with numbers of "white" roots per tiller, species differences were significant at the 1% level from late April until mid November, with the sole exception of early October when significance was attained only at the 5% level. In the case of dry weight of "white" roots per tiller over the same period, the difference between species was significant at only the 5% level on three occasions, and failed to reach significance on two occasions. The analyses based on root weights have consequently not been included in this paper.

On the basis of root numbers, four distinct differences can be seen between the three grasses. Firstly, in the period January to March

following planting out in August there was an appreciable falling away of tillers and root numbers in Italian ryegrass. If this reduction is normal, it shows that late summer and autumn may be critical for the survival of Italian ryegrass. Under such competition as is to be found in a pasture, loss of roots and tillers at this time could be fatal, and particularly so if the dry season were prolonged through late appearance of the autumn rains.

Secondly, the autumn (March) build-up in numbers of "white" roots per plant in Italian ryegrass was slower than in the other two grasses. In all of them "white" roots were first distinguished from darkening older roots on 9 March, but it was not until late April that the numbers of "white" roots per plant in Italian ryegrass became of the same order as in the other two species. This adds further evidence that late summer and early autumn are critical periods for Italian ryegrass.

Thirdly, during winter, Italian ryegrass produced "white" roots in abundance. From the end of June until the end of August, production of "white" roots per plant was extremely high and not until October were their numbers again comparable in the three grasses (Fig. 1). Similarly on a per tiller basis, the numbers of "white" roots in Italian ryegrass were proportionately high. The average value of "white" roots per tiller from 1 June till mid September was of the order of 1.0 in Italian ryegrass, while in the other species for the same period it was approximately 0.4.

This same feature was also shown when the numbers of "white" roots per plant were expressed as a percentage of the total number of roots per plant. In Italian ryegrass this value was greater than 30% from 1 June till 24 August and reached a maximum value during that time of 44%. In both perennial ryegrass and tall fescue, the values approached but never reached 20%.

Fourthly, there were consistently fewer "other than white" roots per tiller in Italian ryegrass than in perennial or tall fescue during winter, despite a higher production of "white" roots over this period.

It is apparent from this that during the period after the middle of April until the middle of September, the root system of Italian ryegrass was composed to a large extent of new and young roots. It is possible that the greater nutritional activities of these new roots could account for at least part of the greater leaf growth in Italian ryegrass during winter as compared with perennial ryegrass.

Root Replacement

This experiment did not permit the examination of individual roots more than once, i.e. at each lifting. No direct evidence was therefore obtained on the length of time that the new roots retained their whiteness. An assessment was made in Italian ryegrass from the increase in numbers of "other than white" roots after mid July following the increases in "white" root numbers during May and early June of some 6 to 9 weeks. There is some evidence that this period is too short for tall fescue, and possibly also for perennial ryegrass.

If two assumptions can be accepted as reasonable, then it becomes possible to prepare figures giving the hypothetical amount of root replace-

ment that occurs in the root system of each species. These assumptions are that the length of time a root retains its white characters and the seasonal cycle of development are comparable in all three grasses. Table 5 sets out the relevant figures. The allowance of 40% calculated in column 3 is a convenient figure adopted here to correct the total "white" root numbers for the fact that white root characters lasted for a period longer than 6 weeks and hence extended over two or more lifting dates.

It is fully realized that the figures given in Table 5 are based on unproved assumptions and may not be the only factors influencing root senescence. These hypothetical figures, however, do support the evidence discussed earlier, particularly that dealing with the prominence of white roots in Italian ryegrass.

TABLE 5. Hypothetical Root Replacement Rates

	Total of Mean Numbers of "White" Roots per Plant	Adjusted Numbers (40%) of "White" Roots per Plant *	Approximate Numbers of Total Roots per Plant in Mid-November	Perennial rye. Replacement of Roots
Perennial rye.	425.3	170	250	68
Italian ryegrass	623.6	250	250†	100
Tall fescue	376.1	150	250	60

* The evidence that new roots remain "white" for a longer period in tall fescue and possibly in perennial than in Italian ryegrass, indicates that this adjusted value of 40% is likely to be excessive, and hence inflates the percentage replacement of roots in tall fescue and perennial ryegrass.

† This value is rather high, since Italian ryegrass had fewer root numbers than the other grasses in mid-November. The effect of allowing for this in the computations would have been to reduce the percentage replacement in perennial ryegrass and tall fescue.

The greater degree of root death and renewal which appears to be operating in Italian ryegrass could also be responsible for the relatively short life of this species. The effect would show more markedly in adverse seasons when environmental conditions which cause a depression in root initiation would also be reducing the size of a root system that has been shown to be so dependent on new root growth.

It is clear from Fig. 1 that soil temperatures in winter in Palmerston North are very suitable for the initiation of new roots. The pattern of new root formation is related inversely to that of soil temperature at the 4-inch level, as recorded at Grasslands Division Meteorological Station, some 300 yards from the trial area. This trial was not intended to elucidate the factors that stimulate root formation, but it would appear that soil temperature plays an important part. The two ryegrasses followed a somewhat similar pattern of root formation during the colder months but the marked peak seen especially in Italian was absent from tall fescue. In all three grasses the peak of new root growth was in July and was sustained longer into spring and early summer in tall fescue than in the ryegrasses.

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A LEAF BREAKDOWN OF TOBACCO ASSOCIATED WITH THE COPPER STATUS OF THE SOIL

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Summary

A breakdown of tobacco leaves as they approach maturity has been corrected by the use of copper sulphate at 50 lb. and 100 lb. per acre; 20 lb. per acre was ineffective and more than 50 lb. gave no worthwhile extra benefit.

Affected leaves are rich in total and protein nitrogen and when flue-cured are low in sugars. Use of copper sulphate reduces the nitrogen content and increases the sugar content. For sound leaf at least 9% of reducing sugars, and not more than 2.05% total nitrogen and 0.90% protein nitrogen, should be present.

Unsound leaves are high in manganese and low in copper; sound leaf contains not more than 130 p.p.m. of the former, or less than 6 p.p.m. of the latter. The ratio Mn/Cu should be less than 28.

INTRODUCTION

In the 1946–47 growing season, attention was drawn to a condition of tobacco appearing on a farm at Marahau, twenty-four miles north-west of Nelson. The trouble had been observed intermittently in previous seasons and, although the total loss was not great, with continuous cropping to tobacco it was becoming progressively more severe each season.

SYMPTOMS

The trouble commences as dull greyish-brown "greasy" looking spots, concentric in formation, located between the veins. The spots vary in size from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. in diameter. They dry out from the centre, turning brown while the surrounding tissue is yellowish green. The disorder usually shows up first towards the tip of the leaf, but eventually all portions of the leaf may become involved. The spots tend to spread and coalesce to form large irregular-shaped patches which dry out to a warm brown colour in which the original spotting can be seen as a marbling effect (Fig. 1). The outstanding characteristic of the trouble is the warm chestnut-brown discolouration like air-dried Burley.

The trouble usually first makes its appearance in the cutters when they are about ready for picking. From there it spreads up the plant as the successive leaves approach ripeness. It appears that a certain degree of development is necessary before symptoms appear, because in late-planted tobacco in the same area evidence of the disorder was correspondingly delayed. Picking the leaf on the early side in an endeavour to get ahead of the trouble is not successful as the leaf breaks down in the kiln, partly as the result of immaturity and partly because of the disorder.

SOIL

Although fairly widely dispersed on the farm, the areas affected all appear to be of one soil type. This is a deep, dark-coloured, free,

Fig. 1.—Breakdown in tobacco leaves (Harrison's Special).

dune sand, which does not represent any named soil type, but is nearest to Tahunanui sand. Although the farm is close to the sea and some of the sand is of marine origin, there is no evidence of high chlorine content. Other areas on the same farm produce excellent leaf but they are all of a different, heavier, soil type.

This dune sand is acid (pH 5.2 to 5.8) and is poor in citric-acid-soluble phosphate and potash. The loss on ignition is small (3.1% in a type sample). Cation-exchange capacity is about 6 m.e.%, with the low base-saturation of about 10%. Total nitrogen content of the type sample was only 0.08%. Other data for soils from Marahau (A and B) and for a healthy soil (C) derived from granite are given below:

Both A and B are affected, B being from the experimental area. Compared with soil C from another part of the district, which produces

Soil	pH	Acid-soluble Copper p.p.m.	Acid-soluble Manganese p.p.m.	Exchangeable Manganese p.p.m.
A	5.2	3.5	32	3.2
B	5.8	2.0	54	1.3
C	6.1	65.0	459	5.7

healthy leaf, soils A and B are extremely poor in copper and manganese; their exchangeable manganese contents are also low, yet they produce affected leaf with high manganese contents. Methods of analysis for copper and manganese are given in Appendix A.

Experimental

In the 1946–47 season, when attention was first directed to the trouble, a simple trial was arranged as a preliminary step towards determining whether the disorder was caused by any deficiency. Zinc sulphate, copper sulphate, iron sulphate, and magnesium carbonate were applied to a late-planted area known to be affected, but where as yet the symptoms had not shown up in the crop. The chemicals were dissolved in water half of which was watered along the rows and the remaining half sprayed on the leaves. Breakdown appeared on every plot.

In the 1947–48 season, following up the supposition that the trouble might be due to a deficiency, two trials were laid down. The treatments are shown in Table 1.

TABLE 1. Preliminary Trials

Treatment		1947–48 Breakdown	1948–49 Breakdown
Copper sulphate	20 lb./acre	Moderate	Severe
Zinc sulphate	20 lb./acre	Moderate	Severe
Manganese sulphate	20 lb./acre	Moderate	Severe

Note: Plants had received a complete fertilizer at planting.

On one area of old tobacco land the trouble had been particularly severe during the previous season. The previous history of this land was: 1939–44, six years continuous tobacco: 1944–45 lupins allowed to seed and fall: 1945–46 lupin regrowth ploughed in: 1946–47 tobacco.

The chemicals were mixed with a quantity of dry sand, sprinkled along the row, and hoed in. Rain fell on the following day. The application was made a month after planting when the tobacco was well established. The same treatments were applied to an area of second-year tobacco, where the breakdown had been apparent the previous

season, i.e. in the first crop of tobacco. Treatments were applied as above two weeks after planting. Breakdown in the crop that year was moderate but in neither trial did any treatment have any beneficial effect.

In the 1948–49 season, the trial was repeated (see Table 1) on an area of black sand that had grown tobacco for two seasons and had shown symptoms of the trouble. On an adjacent farm with a similar soil type, a new area, broken out of stunted gorse and poor grass, was planted with tobacco. A trial using the same chemicals was laid down, the treatments being applied ten days after planting. The disorder was quite severe in both trials and none of the treatments brought about any improvement or any apparent differences in growth.

On one of these areas one row of commercial tobacco had missed the fertilizer through a blockage in the drill. Although both adjoining rows were badly affected, there was no sign of the breakdown in this row. An analysis of the affected leaf indicated a high nitrogen content, although at no time had a high-nitrogen fertilizer been used.

Effect of Variation in Composition of Fertilizer

Reviewing the position before the 1949–50 season, it appeared that no benefit had been obtained from the use of minor elements tested. On the other hand there were definite leads that the cause of the trouble might be in the fertilizer practice; the disorder had been most severe on land high in nitrogen following lupins, the affected leaf was high in nitrogen, and no breakdown occurred where tobacco had inadvertently received no fertilizer. Accordingly a trial was planned directed to the composition of the fertilizer, particularly the nitrogen status. Treatments based on an application of a 3-8-8 (N-P-K) mixed fertilizer at the rate of 1,000 lb. per acre are given in Table 2. The fertilizer was applied with the planting machine as the plants were set out in the field. The growth of the crop reflected the nitrogen content of the fertilizer, the most vigorous growth resulting from the use of mixed nitrogen or nitrate of soda, while dried blood and sulphate of ammonia produced only a fair crop. Plots without nitrogen were very much depressed in growth; however, tobacco grown on super and potash only showed no traces of the disorder which was quite general in all other treatments. When the leaf was cured in the kiln, that from the no-fertilizer and the super and potash plots was bright and of a good texture although small in size. Leaf from all other treatments would be classed as poor greenish tobacco.

As the 1949–50 trials appeared to confirm the possibility of a relationship between the level of nitrogen supply and the disorder, the 1950–51 trials were designed to obtain further information on this aspect. Because the various forms of nitrogen in the 1949–50 tests had produced no differences in the severity of the disorder, it was decided to try different levels of nitrogen rather than different forms. Treatments are shown in Table 2. Except in the case of one treatment, where all the nitrogen was obtained from nitrate of soda, the nitrogen was supplied in equal proportions by nitrate of soda, sulphate of ammonia, and dried blood. Growth was definitely in proportion to the amount of nitrogen present, increasing from a very small crop on the no-fertilizer and super and potash only plots to progressively more growth as the nitrogen increased. This was a particularly good growing season and there was no sign of the breakdown anywhere. In the cured leaf, taking both size

TABLE 2. EFFECT OF FERTILIZERS ON CHEMICAL COMPOSITION OF CURED TOBACCO LEAF LAMINAE AT MARAHAU

Data Expressed on Dry Matter Basis

Season	Treatment	Total Reducing Sugars %	Sucrose %	Total N %	Protein N %	Cu p.p.m.	Mn p.p.m.	B p.p.m.	Mo p.p.m.	Zn p.p.m.	Status of Cured Leaf *	Growth of Plant
1949–50	No fertilizer	16.90	2.43	2.55	1.02	2.0	112	12.2	1.0	49	H	Very small
	P-K	15.50	1.61	2.51	1.17	2.0	93	13.2	1.0	19	H	Small
	N-P-K (N as $NaNO_3$)	0.69	0.15	5.11	1.98	2.1	137	15.0	1.0	49	S	Vigorous
	N-P-K (N as sulph. ammon.)	3.64	0.82	4.43	1.83	3.5	284	12.5	1.0	43	S	Fair
	N-P-K (N as dried blood)	3.63	1.14	4.14	1.88	2.0	217	14.7	0.9	36	S	Fair
	N-P-K (N mixed sources)	1.56	0.63	4.01	1.44	3.1	218	20.6	0.7	50	S	Vigorous
	N-P-K (N mixed sources) plus 2 cwt. K_2SO_4	1.55	1.36	4.25	1.66	3.6	222	13.9	1.0	53	S	Vigorous
1950–51	N-P-K 0-0-0	18.67	2.74	1.45	0.74	8.3	49	—	0.8	66	H	Small
	0-8-8	21.28	2.63	1.46	0.67	9.4	54	—	1.0	52	H	Small
	1-8-8 (mixed sources)	18.00	3.15	1.37	0.63	8.5	46		1.1	54	H	Fair
	1-8-8 (as $NaNO_3$)	22.36	1.56	1.39	0.59	6.2	43		1.0	44	H	Fair
	2-8-8 (mixed sources)	19.99	3.88	1.55	0.67	7.3	53		1.5	55	H	Good
	3-8-8 (mixed sources)	18.06	2.69	1.50	0.73	4.1	41		1.0	40	H Greenish	Very good
	2-12-8 (mixed sources)	17.47	2.49	1.52	0.71	6.3	57		1.6	46	H Best Colour	Good
	2-8-12 (mixed sources)	18.83	4.93	1.55	0.71	5.2	41		1.0	46	H	Good
1951–52	N-P-K 0-0-0	12.23	3.87	1.85	0.90	5.0	66	18.5	0.5	35	H	Small
	0-8-8	11.60	3.54	1.67	0.80	6.9	99	—	—	—	H	Small
	1-8-8 (mixed sources)	6.01	0.80	2.38	0.92	6.9	122				H	Medium
	1-8-8 (as $NaNO_3$)	9.54	2.76	2.14	0.90	6.0	96				H	Medium
	2-8-8 (mixed sources)	8.57	1.39	2.05	0.90	4.0	144				M Greenish	Good
	3-8-8 (mixed sources)	2.87	2.84	2.44	1.18	6.0	193				S Poor leaf	Large
	2-12-8 (mixed sources)	4.75	2.83	2.32	1.02	4.0	191				M Greenish	Good
	2-8-12 (mixed sources)	4.65	2.53	2.20	1.00	3.0	154	12.3	0.5	44	M Greenish	Good

* H = Healthy. M = moderately affected. S = severely affected.

and texture into account, the plots receiving the two-per-cent-nitrogen fertilizer were the best, and of these the 2-12-8 was superior. That receiving no nitrogen, although bright in colour, was small in size, while the tobacco grown on three-per-cent nitrogen tended to be large and dark with a greenish cast.

The fertilizer trial was repeated in the 1951–52 season on the same basis as for the previous year. Growth was again in proportion to the amount of nitrogen present. No fertilizer and super and potash plots only made about half a crop, increasing to a full crop with 3-8-8. There was definite breakdown with the 3% nitrogen, a trace with the 2%, while other plots were clean. Cured leaf from the plots without nitrogen was small but bright and of good texture with no green. On the other hand, leaf from the 3% nitrogen plots contained a high proportion of green and brown. The 2% series tended to be orange with a small percentage of greenish cast. Leaf from both the plots receiving 1% nitrogen was small and bright.

The trials so far, therefore, had indicated that no practical solution could be found by varying the major ingredients in the fertilizer. Reducing the nitrogen to a level where no breakdown occurred resulted in an uneconomical yield of leaf. The fertilizer plots were therefore discontinued.

In Table 2 are presented data for reducing sugars, sucrose, total and protein nitrogen, and for copper, manganese, boron, molybdenum, and zinc in cured leaf laminae for the seasons 1949–50, 1950–51, and 1951–52, all being expressed on the dry-matter basis. In the first season, the main emphasis was on the form in which the nitrogen was supplied (nitrate of soda, dried blood, or sulphate of ammonia), and in the last two on variation in the amount of nitrogen that was provided.

As has already been seen, symptoms were severe in the 1949–50 season, except where no fertilizer or only phosphate and potash were supplied. The data for sugars show that except for these two treatments the reducing sugars and sucrose contents were very low. Nitrogen supplied as nitrate was the most damaging. Use of sulphate of ammonia and dried blood gave the highest content of reducing sugars (3.6%) of the various nitrogen treatments. Wherever nitrogen was used in the fertilizer, the total- and protein-nitrogen contents were high, the former ranging from 4.0 to 5.1% and the latter from 1.4 to 2.0%. The highest figures were obtained with nitrate of soda and the lowest with a fertilizer in which the nitrogen was present as nitrate of soda, sulphate of ammonia, and dried blood in equal parts. Data for mineral content, not given in detail here, showed that use of nitrogen increased the total ash, potash, and lime contents quite appreciably, and the phosphoric acid content somewhat, but had no effect on the magnesia content. Even when no fertilizer was provided, the mineral content of the leaf was quite satisfactory. The pH value of cured leaf was 5.3 to 5.4, which is quite normal for Nelson material.

In the 1950–51 season the reducing sugars and sucrose contents were quite satisfactory. It is noticeable that nitrate of soda, which gave such poor results in 1949–50, in the 1950–51 season gave leaf with high sugar contents. The high sugar contents together with the low total- and protein-nitrogen contents, found throughout this season's samples, are in keeping with the reported absence of the leaf disorder.

Breakdown of the leaf was present in the 1951–52 season, especially where 3% of nitrogen was used in the fertilizer: the chemical data show that the leaf from this treatment contained the lowest percentage of sugars after curing, while its total nitrogen and protein contents were the highest of this season's samples. Addition of extra phosphate or potash to the standard 3-8-8 formula did not overcome the leaf trouble, the cured leaf still being low in sugars and relatively high in nitrogen. Where no nitrogen or only 1% was given in the fertilizer, the leaf was free from the disorder. None of this leaf was particularly rich in sugars however, only about 12% of reducing sugars being present where no nitrogen was used. In this season there is a definite correlation of quality with the chemical data, healthy leaf being associated with relatively high sugars but low nitrogen contents. Sucrose content does not seem to be closely connected with quality, although it tends to be higher in the better grades.

Examination of the data for minor-element content shows that the boron, molybdenum, and zinc levels are not of significance in relation to the condition of the leaf under the present conditions of growing at Marahau, but on the other hand copper is low and manganese high when the leaf is affected by the breakdown. Thus, in the 1949–50 season, breakdown of the leaf was severe: copper is very low and manganese is high. In the 1950–51 season, when there was no appearance of breakdown, the copper is relatively high but manganese content is low. Conditions in the 1951–52 season were intermediate between the other two seasons and, while the copper contents are somewhat similar to those of the 1950–51 season, the manganese figures are neither very high nor very low. Taking the bad season of 1949–50, it is notable that the manganese contents of the good leaf from the no-fertilizer and the no-nitrogen treatments are the lowest for this season and are in the range of manganese contents found in 1951–52 for leaf receiving fertilizer with 1% nitrogen: this leaf was not affected by breakdown. In the 1951-52 season, the only leaf seriously affected with breakdown was that from areas treated with fertilizer containing 3% of nitrogen. On this plot the manganese content was raised to 193 p.p.m., compared with 99 p.p.m. for the healthy leaf receiving no nitrogen, but the same amounts of phosphate and potash. It is interesting to note that on using nitrate of soda the manganese content of the leaf is reduced, when compared with other sources of nitrogen.

Effect of Minor Elements

An analysis of the leaf from the 1949–50 season indicated that the copper level in the affected leaf was below normal. This was not inconsistent with the high nitrogen content of the leaf. Acordingly trials were laid down in 1950–51 and subsequent seasons to determine the effect of copper on the disorder. Treatments are shown in Table 3; these were superimposed on a complete N-P-K fertilizer (3-8-8) applied at 1,000 lb. per acre. The rates given are in terms of the hydrated salts.

In the 1950–51 season, the copper sulphate was applied a fortnight after planting. In one series of plots it was applied dry and hoed in, while in the other it was dissolved in water and watered on. No breakdown occurred anywhere this season and there were no apparent differences in growth as the result of the treatments. In the cured leaf, however, that from the plots receiving copper was brighter and finer

textured than leaf from the control plots, particularly where the copper sulphate was applied in solution.

In the 1951–52 season, other minor elements were included in the trial besides copper. These are shown in Table 3. The chemicals were dissolved in water and applied three weeks after planting. There were no apparent differences in the growth of the various plots. However, those receiving copper had no sign of the breakdown, while all others had a trace, although not severe. The cured leaf from the plot receiving copper was definitely the best; the colour was a rich orange with very little green or brown, and body and texture were good. The plots receiving zinc were the next best, but not as good in any respect as those receiving copper. The leaf from all other treatments was thin with a large proportion of green and brown.

In 1952–53, the trials were confined to copper and zinc as these had given some promise of correcting the trouble. The area available for the trial this season was not particularly suitable, as the incidence of the disorder on it was known not to be severe. Treatments are given in Table 3. No differences were noted in growth and no breakdown occurred on either the treated or the untreated plots. The cured leaf from the plots receiving copper was brighter and of better body and texture than any other.

The same trial was repeated in the 1953–54 season. This time an area where the trouble was known to be severe was secured. The treatments were mixed with a quantity of sand, distributed along the row, and worked in a few days after planting. No differences in growth were noticed, but differences in breakdown were quite marked. The plots treated with copper, either alone or in combination with zinc, were free from the disorder which was present in all other plots. Leaf from all plots was cured in the kiln. Once again the leaf from the plots receiving copper was superior to that without copper, being brighter in colour, heavier bodied, and of a finer texture than the no-copper leaf. There was no difference between the 50 lb. and the 100 lb. dressings, but in general the copper alone was slightly better than the copper with zinc. Leaf without copper tended to be dark and dull with a percentage of brown and green leaf.

A somewhat similar condition has been observed on a farm in the Ngatimoti district. The soil in question is a raw granite sand, while the remainder of the paddock is a heavy silt. Levelling operations some years ago removed the silt from the higher areas exposing the coarser layer beneath. Growth on this area was poor compared with the rest of the paddock. In order to stimulate growth, the tobacco was topdressed with nitrogenous fertilizer. This increased the size of the plant but at the same time accentuated the breakdown. As these symptoms corresponded to those at Marahau it was decided to try a dressing of copper. Accordingly 40 lb. of copper sulphate was applied to the whole paddock. Tobacco was planted on the area, and in spite of a generous fertilizer programme, which included 100 lb. of sulphate of ammonia on the preceding cover crop, no breakdown occurred, although there were signs of it on other areas of the same farm.

Analytical data obtained on material of the 1949–50 season suggested that the copper content of affected leaf was unusually low. Thus the dry matter of affected uncured leaf from a farm adjacent to

TABLE 3. EFFECT OF MINOR ELEMENTS ON CHEMICAL COMPOSITION OF TOBACCO LEAF LAMINAE AT MARAHAU
Data Expressed on Dry Matter Basis

Season	Treatment	Total Reducing Sugars %	Glucose %	Sucrose %	Total N %	Protein N %	Cu p.p.m.	Mn p.p.m.	B p.p.m.	Mn p.p.m.	Zn p.p.m.	Status of Cured Leaf*	
1950–51	No copper. Dry	16.57	—	3.04	1.47	0.68	7.4	73	—	1.1	70	H	
	$CuSO_4$, 20 lb. Dry	19.91	—	3.49	1.15	0.68	6.8	42	—	1.0	53	H	
	$CuSO_4$, 40 lb. Dry	19.06	—	3.99	1.21	0.68	9.6	52	—	1.1	54	H	This area has grown affected crops in the past.
	No Copper. Solution	16.31		5.43	1.63	0.61	7.5	85		2.1	89	H	
	$CuSO_4$, 20 lb. Solution	25.96		3.72	1.36	0.57	6.5	61		1.1	55	H	
	$CuSO_4$, 40 lb. Solution	21.19	—	2.74	1.42	0.83	6.4	56	—	0.5	70	H	
1951–52	All minors used. Solution†	2.98	—	1.61	2.89	1.22	6.3	243	13.6	2.1	52	M	
	$ZnSO_4$, 20 lb. Solution	5.92	—	2.80	2.65	1.08	5.8	248	19.9	0.5	55	M	
	$MnSO_4$, 20 lb. Solution	4.73	—	2.15	2.51	1.02	5.2	250	12.2	0.5	52	M	
	$CuSO_4$ 20 lb. Solution	9.62	—	3.13	2.21	1.01	5.7	168	9.4	0.5	39	H	
	Ammon. Molyb. 1 lb. Sol.	2.23	—	0.71	3.02	1.35	4.6	258	[illegible]	7.2	56	M	
	Borax, 10 lb. Solution	1.46	—	1.51	2.85	1.07	4.2	261	89.4	0.8	50	M	
1952–53	No minor elements	26.42	16.98	5.67	1.58	0.78	3.1	123	7.1	1.5	56	H	
	$CuSO_4$, 50 lb.	24.71	15.09	5.18	1.61	0.84	4.1	75	6.7	0.8	34	H	
	$CuSO_4$, 100 lb.	25.72	14.79	5.87	1.70	0.89	4.7	85	7.0	1.0	42	H	Area has grown slightly affected leaf in other seasons.
	$ZnSO_4$, 50 lb.	24.39	13.53	4.71	1.63	0.84	3.6	105	7.4	1.0	95	H	
	$ZnSO_4$, 50 lb. $CuSO_4$, 50 lb.	26.75	13.72	6.60	1.70	0.84	4.7	97	5.4	1.3	78	H	
	$ZnSO_4$, 50 lb. $CuSO_4$ 100 lb.	26.11	17.29	5.33	1.23	0.71	4.1	60	7.0	1.5	34	H	
1953–54	No minor elements	7.28	4.51	3.33	2.21	0.92	8.5	151	16.7	0.4	35	M	
	$CuSO_4$, 50 lb.	12.82	8.88	4.20	1.85	0.79	8.4	125	12.1	0.3	29	H	
	$CuSO_4$, 100 lb.	14.81	9.77	6.33	1.59	0.76	6.3	112	11.7	0.1	32	H	
	$ZnSO_4$, 50 lb.	10.89	7.01	4.34	2.10	0.93	4.8	119	15.0	0.2	81	M	
	$ZnSO_4$, 50 lb. $CuSO_4$, 50 lb.	13.69	7.97	3.19	1.87	0.90	9.9	104	12.2	0.2	52	H	
	$ZnSO_4$ 50 lb. $CuSO_4$, 100 lb.	13.12	7.19	6.22	1.73	0.89	7.3	83	10.3	0.2	75	H	

* H = Healthy. M = Moderately affected. † Used at half the rates employed for the individual elements.

that where the experimental work has been carried out contained only 4.3 p.p.m. of copper, whereas cured leaf from a different soil type in the same district contained 27 p.p.m. For comparison, two samples of leaf from the Tobacco Research Station in that season contained 27 and 40 p.p.m. of copper. The type of ailment under consideration has never been seen on the last two areas.

Following up the above suggestion that low copper content might be a factor in the incidence of the ailment, trials on a more extensive scale than the pilot trials of the 1946 47, 1947–48, and 1948–49 seasons, were carried out in the four seasons 1950–51 to 1953–54 and have been discussed above. Results of chemical analyses made on samples from these latter trials are given in Table 3. Methods of analysis used for copper and manganese are given in Appendix A.

In the 1950–51 season, using copper sulphate (hydrated) at 20 lb. and 40 lb. per acre, either dry or in solution, the sugar contents of the cured leaves were appreciably increased, especially when the copper was supplied in solution, thus probably assisting early penetration to the root zone and consequent absorption by the plants. Application of copper also reduced the total nitrogen content of the leaves, but increased the proportion of protein nitrogen. Use of copper sulphate had relatively little effect on the copper content of the leaves, but appreciably reduced the already relatively low content of manganese. It has been noted above that leaf from the copper treatments, especially where the solutions were used, was improved in quality. No breakdown occurred on any plots in this season.

A wider range of minor elements was used in the 1951–52 season, namely copper, zinc, manganese (each as hydrated sulphate), molybdenum (as ammonium molybdate), and boron (as borax). Of these, copper was outstanding in raising the sugar content of the leaf, while zinc was next. Copper sulphate, at 20 lb. per acre, applied as a solution, also greatly reduced the nitrogen and manganese contents of the leaves. Leaf from the copper treatment was easily the best, while zinc treatment resulted in some improvement in quality. The other treatments were not useful, giving leaf of low sugar, high nitrogen, and high manganese contents.

While the above rate of 20 lb. per acre of hydrated copper sulphate was beneficial, it was considered advisable to increase the rate of application in later seasons: this was done in the 1952–53 and 1953–54 seasons, the rates being raised to 50 lb. and 100 lb. per acre. Zinc sulphate was again used, also at a higher rate, namely 50 lb. per acre.

In the 1952–53 season no leaf breakdown occurred, but the leaf from the copper treatments was judged to be of better quality than that from the control and zinc treatments. All the leaf was sufficiently rich in sugars and low in nitrogen for satisfactory quality. Copper content has been slightly increased and the manganese content somewhat reduced by use of copper sulphate. Zinc sulphate has also reduced the manganese content whether used alone or in conjunction with copper sulphate.

In the 1953–54 season, leaf breakdown was present in leaf receiving only the standard fertilizer, or this fertilizer in conjunction with zinc sulphate. The affected leaf was low in sugars and relatively high in

nitrogen and manganese contents. Use of zinc sulphate was beneficial to quality but not to the same extent as copper sulphate. When used at the rate of 50 lb. per acre, the copper sulphate increased the sugar content of the leaf, appreciably when used alone, and to some extent when applied in conjunction with zinc sulphate at the same rate. Nitrogen and manganese contents were reduced by applications of copper sulphate. When used at 100 lb. per acre, the copper sulphate was still more effective in improving the quality, raising the sugar content, and reducing the nitrogen and manganese contents, when used either alone or in conjunction with zinc sulphate. It is noticeable, though, that the proportion of protein nitrogen present was increased by use of copper sulphate. Zinc sulphate exerted a similar effect to a slight extent. It is interesting to note that the two rates of application of copper sulphate reduced the manganese content by nearly the same amounts whether used alone or in conjunction with zinc sulphate.

It is clear from Table 3 that use of boron, zinc, and molybdenum increased the amounts of these elements in the leaves. Copper applications decreased the boron, manganese, and zinc contents, while zinc sulphate at the higher rates of application reduced the manganese and boron contents. Molybdenum content was relatively stable. As was seen in the fertilizer trials, the levels of boron, zinc, and molybdenum do not appear to be a factor in the incidence of breakdown in the leaf.

Effect of Season

There appeared to be no direct correlation between seasonal conditions and the appearance of the disorder in the field. In the two seasons where the trouble was absent or very slight there was a high February rainfall. On the other hand, February was dry in the two seasons in which there was the greatest amount of breakdown. There appeared to be no other consistent correlation, and it is doubtful if the February rainfall has any significance. The fact that the trials had to be carried out on a different area each season prevented direct comparisons being made. In general it could be said that the trouble was more apparent in adverse growing seasons and less under favourable growth conditions.

Discussion

The trials carried out indicate that the leaf breakdown described is associated with a low copper content of the dry matter. Although certain growth characteristics suggested an excess of nitrogen, the experiments indicate that the leaf breakdown is caused by the shortage of copper, one result of copper deficiency being an unusually high uptake of nitrogen. Applications of 50 lb. of copper sulphate per acre corrected the trouble. No benefit appeared to be gained by increasing the quantity beyond this, but 20 lb. was insufficient for consistently satisfactory results.

The data presented above show quite clearly that the incidence of breakdown of tobacco leaf found at Marahau, and on certain other areas in the Nelson District, is very sensitive to the carbohydrate, nitrogen, copper, and manganese status of the plants. Symptoms seen in Nelson are not those associated with copper deficiency in tobacco as described by other workers. Too low a supply of copper is stated to cause a more or less permanent wilting of the top leaves; no mention is made of any leaf damage[1]. The copper content of leaves showing wilting

does not seem to have been reported. It is of interest, however, to note that most of the data for copper content of leaves at Marahau fall well below the figure of 10 p.p.m., which has been given as probably being satisfactory[2]. Symptoms of copper deficiency do not seem to have been reported in field-grown tobacco crops, but reports of increased yield and improved quality following the use of copper sulphate are to be found. As has been seen, applications of zinc sulphate, although sometimes slightly beneficial, have not been effective in overcoming the damage to the leaves. Absorption of zinc by the plants from these applications was appreciable. The concentration of zinc in the leaves at Marahau is much greater than the minimum requirement of less than 10 p.p.m. suggested by Bacon *et al.*[3] Published data for manganese content vary widely. Large amounts, much greater than those found in the samples of the present investigation, can apparently be present without causing any visible symptoms of disturbed nutrition.

According to Lucas[4], sub-optimal supply of copper produces a plant with unusually large amounts of total and protein nitrogen in the dry matter, and an increase in the proportion of protein nitrogen. At Marahau, the nitrogen contents are certainly abnormally high in affected leaf, but the proportion of protein nitrogen is lower in such leaf than in healthy leaf produced by use of copper sulphate. Tobacco leaf (cured) from Marahau therefore does not follow completely the pattern of nitrogen distribution of the crops grown by Lucas.

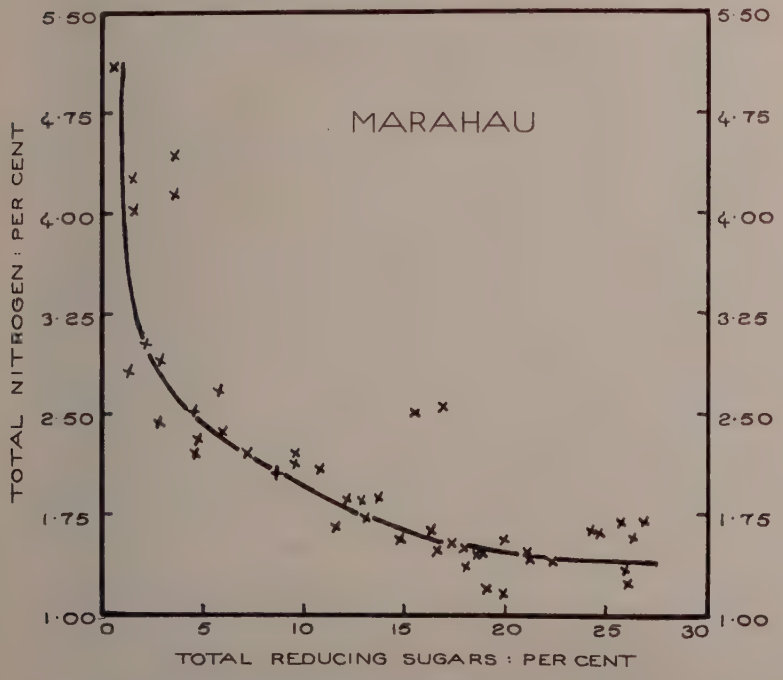

Fig. 2.—Relationship between total nitrogen and total reducing sugars in laminae of cured tobacco leaf.

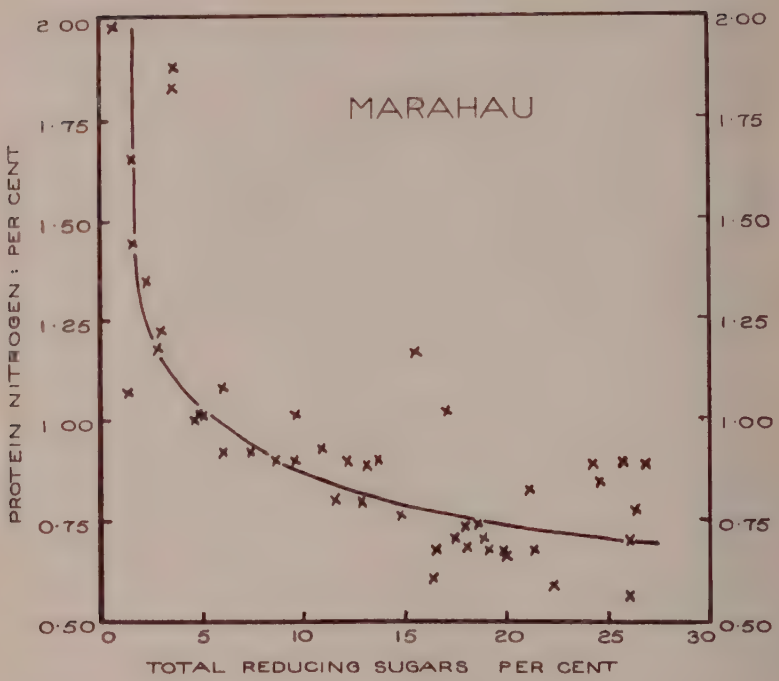

Fig. 3.—Relationship between protein nitrogen and total reducing sugars in laminae of cured tobacco leaf.

When the percentages of total reducing sugars and total nitrogen in the samples analysed are plotted, it is at once apparent how greatly the nitrogen and sugar contents are inter-dependent (Fig. 2). Very low sugar contents are found with high values for total nitrogen. A corresponding graph (Fig. 3) shows the same relationship to hold for protein nitrogen. Close examination of the data for reducing sugars in relation to condition of the cured leaves shows that a level of 9% of reducing sugars is required for healthy leaf under the conditions of growth at Marahau. This covers all five seasons of the experiments, whether all leaf or only some leaf was sound in any particular season. Correspondingly it would appear that sound leaf was obtained when the total- and protein-nitrogen contents were not greater than 2.05% and 0.90% respectively, except for two samples of small sound leaf from the 1949–50 season.

It is of considerable interest to examine these boundary figures for sugars and nitrogen contents in relation to the copper and manganese contents. In deciding the dividing levels (between sound and unsound leaf) of the copper and manganese contents and their ratios, particular importance has been given to their relationship to the figure of 9% of reducing sugars found to be necessary for the production of sound leaves.

Sugar Content

Copper content. If the data for the two seasons 1950–51 and 1952–53, which produced sound leaf on all treatments, are excepted,

there is a definite tendency for copper content to increase with increase in sugar content. About 6 p.p.m. of copper is necessary for development of healthy leaves. Some samples of unsound leaf have copper contents greater than this, but the majority are below this level. In the 1950–51 season all samples except two were above this level. For 25 samples from the seasons in which breakdown occurred, the regression equation is y(Cu p.p.m.) = 0.242 x (reducing sugars %) + 3.65. The correlation coefficient, r = 0.58, is highly significant (P = 0.1% nearly).

Manganese content. Only one sample of unsound leaf contained less than 130 p.p.m. of manganese. Sound samples, especially those from seasons when no breakdown occurred, were usually at a level of less than 100 p.p.m. When data for 27 samples from the three season 1949–50, 1951–52, and 1953–54, in which breakdown occurred, are plotted, a very distinct correlation of high manganese content with low sugar content is revealed, r = —0.59, P = 0.1% nearly. The regression equation is, y (Mn p.p.m.) = 239 —9.67 x (total reducing sugars %). The regression is valid into the region of sound leaf with sugar content up to 17%.

Mn/Cu ratio. When the values of this ratio are high, the content of reducing sugars is low. Unsound leaf is obtained when the value of this ratio is less than 28. Healthy leaf showed values ranging, with few exceptions, from 5 to 20.

Total Nitrogen Content

Copper content. Only three samples with more than 6 p.p.m. of copper in the dry matter showed nitrogen contents greater than the suggested limit figure of 2.05%, but an appreciable proportion of the total number of samples of sound leaf had less than 6 p.p.m. of copper. These latter were however outnumbered by the unsound leaves of relatively high nitrogen content.

Manganese content. Using the limiting figure of 130 p.p.m. for sound leaf it is found that only 4 out of 31 samples fulfilling this condition contain more than 2.1% of nitrogen. A high positive correlation, r = 0.746 (P = 0.1%), is shown between increased manganese and increased nitrogen contents; the regression equation is, y (total N) = 0.0097 x (Mn. p.p.m.) + 0.956.

Mn/Cu ratio. Using the limiting figure of 28 for this ratio it is found that practically all the samples with values below this figure fall into the healthy class of leaf with less than the limiting nitrogen content of 2.05%. There is a highly significant (P = 0.1%) positive correlation (r = 0.876) between increasing values of total nitrogen and the Mn/Cu ratio. The regression equation is y (N%) = 0.0338 x (Mn/Cu) + 1.20.

Protein-nitrogen Content

Copper content. Protein nitrogen is generally high when copper content is low. A few samples with less than 6 p.p.m. of copper and less than the limiting 0.90% of protein nitrogen represented sound leaf. Only one sample with more than 6 p.p.m. of copper returned more than 0.92% protein nitrogen.

Manganese content. For values of protein nitrogen below 1.5%, excluding four samples, there is a highly significant (P = 0.1%) positive correlation (r = 0.727) of high manganese with high protein content. Only four samples with manganese contents of less than 130 p.p.m. show protein-nitrogen figures in excess of 0.90%, two of these exceed this limiting figure by a very small margin. The regression equation between protein-nitrogen percentage (y) and Mn content in p.p.m. (x) is $y = 0.00352 x + 0.525$.

Mn/Cu ratio. Only three samples of leaf with values of this ratio less than 28 contain more than 0.90% protein nitrogen. A highly significant (P = 0.1%) positive correlation (r = 0.857) between increasing values of the ratio (x) and protein nitrogen (y) is found; the relevant regression equation is, $y = 0.012 x + 0.62$.

Ratio of Protein Nitrogen to Total Nitrogen

No certain relationship appears to exist between the values of this ratio and the contents of copper and manganese, but low values of the ratio Mn/Cu, and thus good quality in the leaf, tend to accompany high values of the PN/TN ratio. Values of this ratio range from 36% to 59%. For 10 of 14 treatments receiving copper, this ratio is 48% or more.

It is clear from the above discussion that, although manganese is a controlling element in deciding the directions in which the levels of sugars, total nitrogen, and protein nitrogen move, it is copper which on application to the plants brings about normal growth. It may be noted also that higher copper contents are associated with lower manganese contents. But the ratio of copper to manganese is of still greater importance in deciding the condition of health of the plant than the levels of either copper or manganese by themselves, although in those seasons when no breakdown occurred the manganese content, except for two samples, did not exceed 100 p.p.m. Seasonal variations have been seen to be very great, but the factors causing them have not been determined.

There are two possible ways, other than as a direct nutritional element to the plants, in which the added copper may function: (1) by acting as a catalyst in the soil to oxidize the manganese and thus to reduce the intake of manganese by the plants, and (2) by reducing the rate of nitrification of soil organic nitrogen, thus reducing the intake of nitrogen by the plant. The former is a more likely effect than the latter, especially since the organic-matter content of the soil is so low, loss on ignition being only 3.0% in the topsoil. Because of the very low acid-soluble-copper content of the soil (2.0 p.p.m.) it would seem that any effects from the above two possible actions are secondary to the direct nutritional effect of the added copper.

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Appendix A. Methods of Analysis

Total Copper in Soil. 1 g. of soil is digested in an 8 in. × 1 in. Pyrex test tube with 5 c.c. of an acid mixture (1 vol. 60% perchloric acid, 1 vol. sulphuric acid and 3 vols. water). Later, 1 c.c. of conc. nitric acid is added during the digestion. When digestion is completed, water is added and the liquid made distinctly alkaline with ammonia. To develop the colour for determination 1 c.c. of a solution of sodium diethyldithiocarbamate (0.01%) in ammonium citrate is added and the total volume is made up to 25 c.c. with water. The coloured complex is extracted by shaking with 5 c.c. of amyl alcohol. By comparison with a standard curve the amount of copper present is determined.

For determining the copper content of the tobacco leaves essentially the same procedure as above is followed using 0.5 to 1.0 g. of ground material.

Manganese in Soil. Total manganese was determined by digestion to fumes with concentrated sulphuric acid, the residue being taken up in 10% sulphuric acid after filtration. Potassium periodate is added to oxidize manganese to permanganate, the amount finally present being determined colorimetrically.

For exchangeable manganese content, the soil was extracted with N neutral ammonium acetate solution, and the extract was evaporated in the presence of some sulphuric acid to fumes. After digestion with 10% sulphuric acid, the manganese was oxidized with periodate and determined colorimetrically as permanganate.

The manganese content of the leaves was determined by ashing 1 g. (or less if desirable) of ground material, laminae only, digesting the ash in 10% sulphuric acid, and, after filtration, oxidizing the manganese with periodate. The amount of permanganate so formed was determined colorimetrically by direct comparison against freshly made standards.

THE ANATOMY OF THE VEGETATIVE SHOOT OF *Paspalum dilatatum* Poir

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(*Received for publication, 28 October 1955*)

Summary

The anatomy of the leaf and of the stem apex of *Paspalum dilatatum* is described and compared with that of *Lolium perenne*.

The paspalum leaf has a higher proportion of vascular and sclerenchymal tissue and a lower proportion of mesophyll. The latter is compact with less intercellular space. The bundle sheath is single-layered and contains large chloroplasts. The stem apex is smaller and there are fewer leaf primordia in the meristematic zone behind the apex.

Introduction

On the basis of floral organization, the Gramineae are divided into two major groups, the Pooideae and the Panicoideae. *Lolium perenne* belongs to the former and *Paspalum dilatatum* to the latter. In addition, perennial ryegrass grows best under cool temperate conditions whereas paspalum is adapted to sub-tropical conditions. This work was undertaken to compare the anatomy of these two widely different grasses.

In this paper the anatomy of the leaf and of the stem apex of paspalum is compared with that of perennial ryegrass, which was described in a previous paper (Soper and Mitchell, 1956). The two species were grown under the same conditions, that is, in full daylight at a mean temperature of 58°F. The effects of a combination of shading and higher temperature on the anatomy of the shoot and leaf will be reported in a later paper.

Material and Methods

These were as described for perennial ryegrass (Soper and Mitchell, 1956) except that dimensions of cells of the lower epidermis were measured from logitudinal sections instead of from strips of epidermis, which are difficult to prepare from paspalum leaves. Vessel length was not recorded.

The Leaf Blade

The structure of the leaf blade differs from that of perennial ryegrass in several respects. The upper surface is not ridged (Fig. 1) and its epidermis is composed almost entirely of large, thin-walled bulliform cells. On the upper side of the main vein there is a midrib of colourless parenchyma cells. Stomata occur not only on the upper surface of the blade, to which they are confined in ryegrass, but also on the lower surface.

When grown in full daylight at 58°F. paspalum has much shorter, wider leaves with four to five times as many veins across them (Table 1 and Fig. 1). Sclerenchymal strands are more numerous, being present above and below all but the smallest vascular bundles as well as along the edges of the blade. The higher proportions of vascular and sclerenchymal tissues add to the rigidity of the blade.

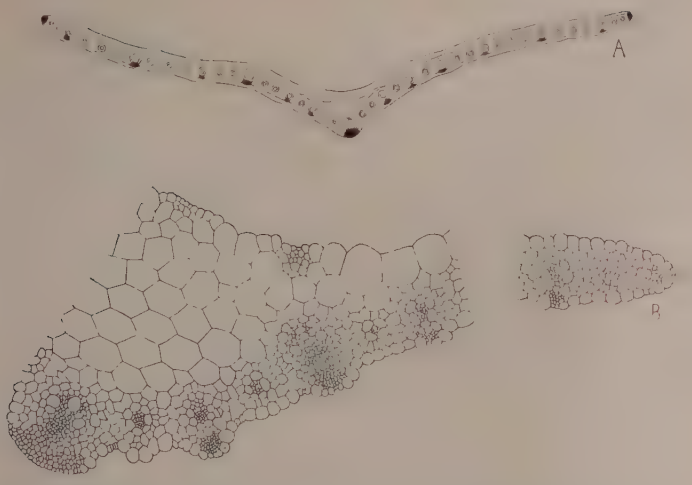

Fig. 1.—Transections of the leaf blade. A. Diagram of leaf three. Fibre strands shown in black. (× 25). B. Part of the leaf on a larger scale (× 80), including the median vein, one large lateral vein and five intermediate veins, and two veins at the edge of the leaf.

TABLE 1. DIMENSIONS OF LEAF BLADE OF PASPALUM
Means and Standard Deviations given for 6 Leaves

	Length (cm.)	Width at Base (cm.)	Area of Blade (sq. cm.)	Thickness at Base* (cm.)	Cross-Sectional Area (sq. cm.)	No. of Vascular Bundles across Base
Leaf 3	2.2 ± 0.4	0.38 ± .04	0.77	0.015 ± .002	0.0056 ± 0.0008	36 ± 6
Leaf 6	3.8 ± 0.2	0.72 ± .02	2.71	0.017 ± .002	0.0118 ± 0.0010	78 ± 4

*Measured through largest lateral vein.

TABLE 2. PROPORTIONS OF TISSUES IN LEAF BLADE (PERCENTAGES OF CROSS-SECTIONAL AREA OCCUPIED)
Means, and in most cases Standard Deviations, given for 6 Leaves

	Epidermis	Mesophyll (excluding Sheath)	Bundle Sheath	Mesophyll (including Sheath)	Vascular Tissue	Sclerenchyma	Rib Parenchyma
Leaf 3	36.2 ± 3.1	41.3	9.0	50.3 ± 2.5	7.3 ± 0.9	2.9 ± 0.4	4.8 ± 0.6
Leaf 6	32.3 ± 1.8	45.3	8.6	53.9 ± 2.0	5.9 ± 0.8	2.0 ± 0.3	5.0 ± 1.3

Table 2 shows that the proportion of epidermal tissue is similar to that for perennial ryegrass (Soper and Mitchell, 1956). Paspalum, however, has 10% less of the cross-sectional area occupied by mesophyll

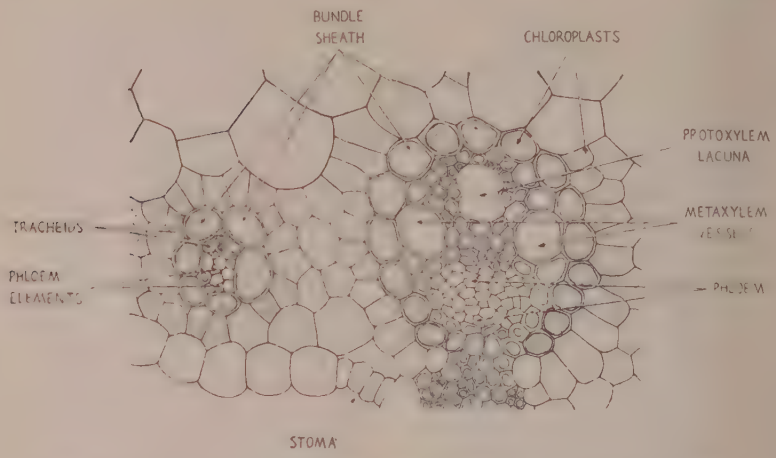

Fig. 2.—Part of the leaf in cross-section, showing on the right a large bundle with vessels in the xylem and sieve tubes in the phloem; and on the left a small bundle with tracheids in the xylem and the phloem represented by parenchyma. (× 340).

tissue, which includes the bundle sheaths. The mesophyll is compact and there are few intercellular spaces except over or beneath the stomata (Fig. 1B and 2). In contrast to ryegrass, there is no inner fibrous sheath about the vascular bundle, and the single-layered, thin-walled sheath consists of cells containing large and conspicuous chloroplasts. Unlike ryegrass, the cells of the sheath are not elongated parallel to the bundle (Table 3), but are similar in size to the other mesophyll cells. There are no bundle-sheath extensions. The sheath tissue constitutes about a fifth of the total mesophyll tissue (Table 2), a much higher proportion than in ryegrass.

TABLE 3. CELL DIMENSIONS AND NUMBERS AT BASE OF LEAF BLADE
Means and Standard Deviations given for Cell Dimensions (μ), n in brackets.

Lower Epidermis

	Length (60)	Width (30)	Depth (30)	Number across Base	Estimated Number along Blade	Estimated Total Number of Cells in Blade
Leaf 3	105 ± 28	23 ± 2	23 ± 2	173	210	29,400
Leaf 6	100 ± 38	23 ± 2	20 ± 2	313	380	96,300

Other Cells

	Mesophyll Cell Length (240)	Bundle Sheath Cell Length (120)
Leaf 3	22 ± 6	23 ± 7
Leaf 6	19 ± 4	24 ± 10

Cells of the lower epidermis are less than a quarter of the length of those of perennial ryegrass but of similar width so that, though the blade is shorter than that of ryegrass when grown under the conditions described above, there are more cells along it and, since it is wider, a greater number of cells across it. The total number of lower epidermal cells in the blade is therefore much greater in paspalum than in ryegrass.

The Stem Apex and Meristematic Regions

TABLE 4. DIMENSIONS OF STEM APEX
Means and Standard Deviations given for Diameters of 6 Apices

Number of Leaves on Main Stem	Diameter (mm.)	Circumference (mm.)	Cross-Sectional Area (sq. mm.)	Width of Cells (μ)	Height of Cells (μ)	Number of Cells across Diameter	Number of Cells from Tip to Point of Measurement
5	0.048 ± .008	0.151	0.0018	7.6	7.5	5–7	2–4
8	0.050 ± .010	0.157	0.0020	6.6	7.0	7–8	3–4

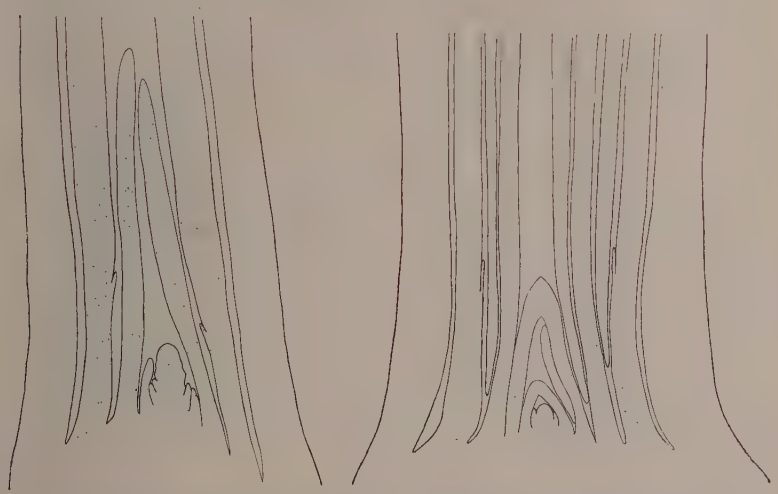

Fig 3.—Diagrammatic median longitudinal sections through the stem apices and immature leaves of paspalum (right) and perennial ryegrass, showing the relative sizes of the two apices. In paspalum the developing leaf overlaps at the edges and is therefore cut in three or four places. Meristematic tissue stippled (× 40).

The stem apex of paspalum is much smaller than that of perennial ryegrass (Fig. 3). Its dimensions are recorded in Table 4. The circumference is only about three-fifths that of ryegrass. The cells in the apex are approximately the same size or smaller and there are fewer of them.

The subapical region is not elongated to form a column of meristematic tissue and bears only one leaf primordium at a time instead of three or four as in ryegrass (Fig. 3). There are, however, more leaves elongating at one time.

Fig. 3 shows that in paspalum each meristematic leaf is cut in more than two places, indicating that there is a considerable overlap of the edges of the leaf. No such overlap occurs in perennial ryegrass.

Discussion

The Leaf Blade

In the leaf blade the differences between the two grasses are best evidenced by the differences in the proportions of the tissues and the differences within the tissues, particularly in the mesophyll. Although the proportion of the cross-sectional area occupied by the mesophyll is lower than in ryegrass, the actual proportion of mesophyll cells may be no less, since the intercellular spaces are few and small compared with ryegrass. A factor in the formation of intercellular spaces is the continuation of cell elongation in the epidermis after cell division has ceased in the mesophyll (Soper and Mitchell, 1956). In paspalum the cells of the lower epidermis elongate to less than one quarter the length of those in ryegrass; therefore it could be expected that there is much less pulling apart of the mesophyll cells. Whatever the cause, the mesophyll is compact with extensive contact areas between the cells. This should facilitate extravascular translocation in the leaf blade in the absence of bundle sheath extensions (Wylie, 1952). The parenchymatous midrib probably also aids in conduction.

With reference to the occurrence of bundle sheaths, the Gramineae may be divided into two groups (Esau, 1953 p. 431). The Pooideae, which includes ryegrass, have double sheaths, while the single-layered sheath found in paspalum is characteristic of the Panicoideae. In ryegrass, the inner sheath contains no chloroplasts and those in the outer are fewer than in the rest of the mesophyll but are otherwise not visibly differentiated. In paspalum, bundle sheath tissue constitutes a much higher proportion of the total mesophyll than in ryegrass, and, since the chloroplasts in its cells are large and densely-packed, this tissue must play an important part in photosynthesis. Esau (1953 p. 431) suggests that these chloroplasts are the only plastids in the leaf concerned with forming starch during active photosynthesis.

The Shoot Meristems

The stem apex of paspalum is smaller than that of ryegrass. The subapical region bears fewer leaf primordia at one time, but more leaves are elongating concurrently. Under the conditions of growth considered here, the rate of emergence of successive leaves on the main stem is only a little slower in paspalum than in ryegrass. In paspalum there is thus a shorter interval between the initiation of a primordium and the commencement of its rapid elongation above the apex. This is presumably due to more rapid cell division. This conclusion is supported by the fact that, although the blade of the mature leaf of paspalum grown under the same conditions is only one third of the length of that of ryegrass, there are more cells along it, that is, more cell division takes place during the development of the leaf.

The overlapping of the leaf edges in paspalum occurs very early in the development of the leaf. It is due partly to the overlapping of the edges of the collar which is formed round the apex by the lateral spread of cell division in the primordium, and subsequently to the activity of the marginal meristem which increases the overlap. Sharman (1942) describes a similar situation in *Zea mays*. No overlap occurs in perennial ryegrass but is frequently found in other strains of ryegrass e.g. "short-rotation".

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NOTE ON THE AUTUMN DECLINE IN LIVEWEIGHTS OF GRAZING EWES

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Summary

Depressions in liveweight gain in autumn of mature ewes on ample pasture are not related to breed differences, stage of reproductive cycle, or to their plane of nutrition or previous nutritional status.

It is suggested that nutritional deficiencies of a qualitative nature in the herbage of the improved pastures are responsible for this check in thrift.

Ewes maintained during the 1951–52 "fat-lamb" season at liberal standards of grazing for milk production studies[2] showed marked temporary depressions of liveweights (averaging 7.5 lb. ranging from 2 to 17 lb. in autumn when weights appear to be normally increasing. These observations pertain to 5-year-old Romney and Cheviot × Romney cross ewes stocked at the rate of 5 to 7 ewes per acre on heavily top-dressed ryegrass—white clover pasture (i.e. "fat lamb" conditions) as well as to Romney ewes at a low nutritional plane on similar country (i.e. 10 to 11 ewes to the acre). Graphs showing liveweight changes of these and certain other experimental groups of ewes are presented in Figs. 1 and 2.

That these observations are not exceptional is indicated by the earlier records of Clarke[3] and Clarke, Barton, and Wilson[4] with groups of ewes on the same experimental plots as the groups of animals described in this paper. During the four consecutive seasons 1940–43, ten groups each of 20 or 25 ewes were followed and depressions in liveweight in autumn were evident in most of the groups. Depressions were less prounounced, however, in another five groups recorded during the 1944–46 seasons, i.e. until 4½ years old. The magnitude of the decline varied considerably between groups and between seasons. Furthermore, the first appearance of a check in rate of gain varied from mid February to late April, but part of this variation could be accounted for by the actual date on which the monthly weighing was made.

Suckling[7] has recorded liveweights of ewes on steep hill country (Te Awa), the carrying capacity of which has been raised from 1½ to 3½ ewes per acre by means of oversowing and topdressing. Autumn liveweight depressions occurred sporadically and were not as pronounced as those already described for "fat lamb" farming conditions, and the effect had practically disappeared from growth curves of Te Awa ewes in later seasons (Mr. F. E. T. Suckling, pers. comm.).

Lack of thrift in ewe hoggets in autumn has also been reported by farmers. Results of experiments at the Ruakura Hill Country Research Station (1952–1954)[1] with hoggets on ample pasture indicate that it is

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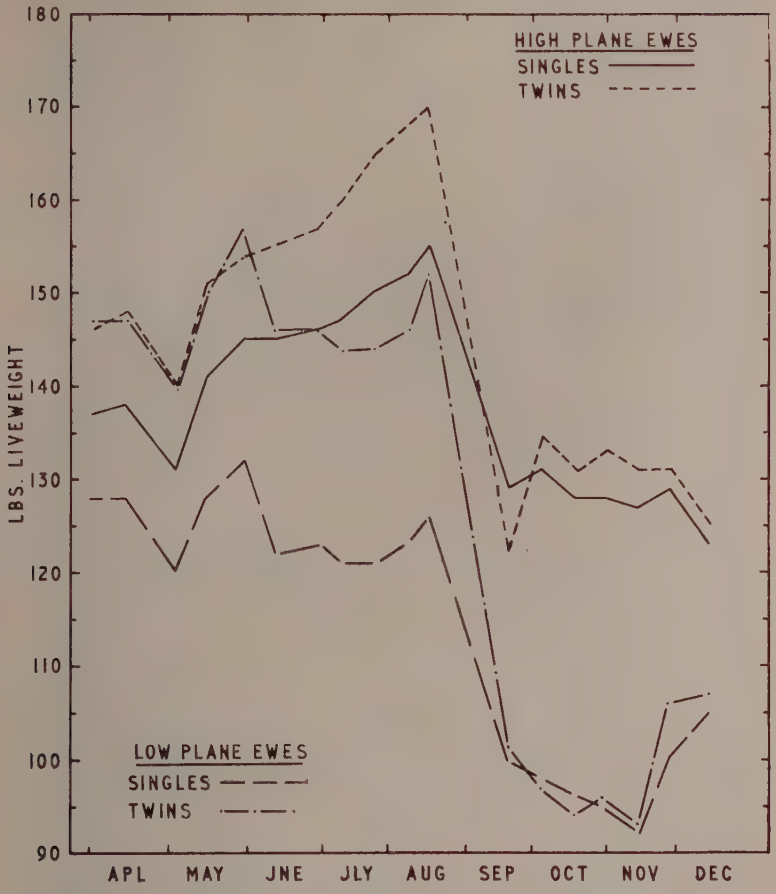

Fig. 1.—Liveweights of 5½-year-old Romney ewes (single- and twin-bearers) grazing at high and low planes of nutrition.

not due to parasitism but is apparently of nutritional origin. Lack of thrift in autumn in hoggets and older ewes may originate from the same cause, but results obtained with younger ewes may be complicated by the extra demands of growth.

Factors responsible for lack of thrift in grazing ewes in autumn may be related to the following:

Reproductive cycle. It is unlikely that this is a predisposing factor since (a) weight declines were often apparent at the commencement of mating (about 20 March in this district) or even beforehand; and (b) the maximum check in liveweight varied from mid February to late April.

Breed differences. It was evident in Romneys of three different "saleyard strains" as well as in ½ and ¾ Cheviot × Romney cross ewes (Fig. 2).

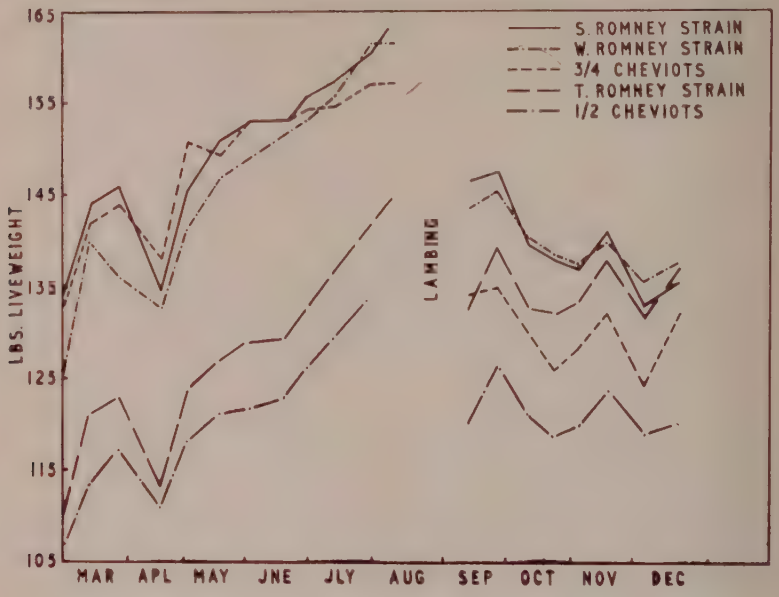

Fig. 2.—Liveweights of 5½-year-old Romney and Cheviot × Romney cross ewes (twin-bearers).

Nutritional factors: (a) *Quantitative*. It is shown in Fig. 1 that the decline occurred with ewes maintained under liberal as well as with those under inadequate standards of grazing. Moreover, a low nutritional plane previously did not appear to aggravate it since underweight ewes behaved similarly to others (T group Fig. 2). This group, initially more than 20 lb. lighter than other groups of Romney through underfeeding, attained the same weight at the end of the experiment.

(b) *Qualitative*. Autumn declines in liveweight of mature ewes occurred most often, however, under "fat lamb" grazing conditions which, judged by the pasture supply, were liberal. It is therefore possible that variations in quality of the pasture were responsible. That such a suggestion is worth considering is supported by the fact that it is now well established that other problems in livestock thrift on improved pastures occur at this time of the year. Ryegrass, following certain unusual weather conditions, causes facial eczema in sheep, possibly because of the presence of toxic substances arising from deranged nitrogen metabolism[5]. Clovers, which tend to preponderate in improved pastures from late summer onwards, contain low concentrations of vitamin E (α tocopherol) which results in a decrease in the efficiency of the conversion of carotene from the pasture to vitamin A in the ruminant animal.[6]

Autumn decline in liveweight of mature ewes may therefore arise from nutritional deficiencies of a qualitative nature in the herbage of improved pasture.

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